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# RESEARCH MEMORANDUM

## ALTITUDE PERFORMANCE CHARACTERISTICS OF THE J47-25 TURBOJET ENGINE - DATA PRESENTATION


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RESEARCH MEMORANDUM

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# ALTITUDE PERFORMANCE CHARACTERISTICS OF THE J47-25 TURBOJET ENGINE - DATA PRESENTATION

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## SUMMARY

An investigation was conducted in an altitude test chamber at the NACA Lewis laboratory to determine the altitude performance of the J47-25 turbojet engine operating with a fixed-area exhaust nozzle. Data were obtained over a range of engine-inlet Reynolds numbers corresponding to altitudes from 18,000 to 54,000 feet and flight Mach numbers from 0.50 to 1.10.

Reducing the engine-inlet Reynolds number resulted in a reduction in corrected air flow but had essentially no effect on corrected exhaust-gas total temperature, corrected fuel flow, and engine pumping characteristics for a range of Reynolds number indices from 0.80 to 0.30. The corrected jet thrust parameter generalized throughout the range of engine-inlet Reynolds numbers investigated.

At a given corrected engine speed with critical pressure ratio existing in the exhaust nozzle, increasing the engine-inlet ram-pressure ratio from 1.0 to 1.25 decreased the corrected exhaust-gas temperature. Further increases in ram-pressure ratio had no effect on the exhaust-gas temperature.

## INTRODUCTION

An investigation was conducted in an NACA Lewis altitude chamber to determine the altitude performance characteristics of a J47-25 axial-flow turbojet engine over a range of engine-inlet Reynolds number indices corresponding to altitudes from 18,000 to 54,000 feet and flight Mach numbers from 0.50 to 1.10. In order to simplify the procedure in obtaining performance data and to make the data applicable to any flight condition, Reynolds number index $\frac{\delta_1}{\varphi_1 \sqrt{\theta_1}}$, which is proportional to Reynolds number at a given corrected engine speed and is a function only

[redacted]

of engine-inlet total pressure and temperature, was used instead of various set altitudes and flight Mach number combinations (reference 1). By the technique just mentioned, the data obtained in this investigation may be used to obtain the performance of the engine at any flight condition for which critical flow exists in the exhaust nozzle. An example 2625 is included in the appendix to illustrate the method of obtaining conventional performance parameters for a given flight condition from the data such as presented herein.

In addition to the basic engine performance, data were obtained in which the effects of variation of engine-inlet conditions on exhaust-gas temperature and thrust were observed. These effects are of importance from the standpoint of aircraft take-off and day-to-day weather variations.

All performance data obtained in this investigation are presented in both graphical and tabular form.

## APPARATUS

### Engine

The J47-25 axial-flow turbojet engine used in this investigation has a twelve-stage compressor, eight tubular combustion chambers, and a single-stage turbine. The engine has a static sea-level thrust rating of 6060 pounds at the rated engine speed of 7950 rpm and an engine manufacturer's turbine-outlet temperature of 1245° F. The compressor air flow is approximately 104 pounds per second and compressor pressure ratio is 5.3 at rated sea-level conditions. A conical exhaust nozzle having an area of 298.5 square inches was installed on the engine. Operation of the engine with this nozzle produced an average tail-pipe total gas temperature of 1710° R (1250° F), which is based on NACA instrumentation at static sea-level conditions and rated engine speed of 7950 rpm. The maximum dimensions of the engine are a 37-inch diameter and a 144-inch over-all length excluding the cylindrical tail pipe and the exhaust nozzle. The total weight of the engine is 2653 pounds.

### Installation

The altitude test chamber in which the engine was installed is 10 feet in diameter and 60 feet in length. The test chamber is divided into three sections separated by bulkheads: the air-inlet section, the engine compartment, and the exhaust section. The engine was mounted on a thrust-measuring bed. A front bulkhead, which incorporated a labyrinth seal around the forward end of the engine, provided for freedom of movement of the engine in an axial direction. A rear bulkhead was installed to act as a radiation shield and to prevent recirculation of the hot exhaust gases about the engine.

## Instrumentation

The location of the instrumentation stations before and after each of the principal components of the engine is shown in figure 1. Sketches showing the arrangement of the separate temperature and pressure probes within a given station are presented in figure 2. The total-pressure tubes at stations 1 and 9 were located at the centers of 24 and 6 equal areas, respectively. The thermocouples at stations 1,
2625 3, 5, and 9 and the total-pressure tubes at stations 3 and 5 were located on approximately equal spacings. The instrumentation at the engine inlet (station 1) was used in calculating the altitude and flight Mach number correction factors $\theta$, $\delta$, and $\varphi$. (All symbols are defined in the appendix.) The pressure and temperature measurements at station 9 were used to calculate ideal or rake jet thrust and nozzle gas flow. Measured jet thrust was also determined from scale readings for each condition investigated. The atmospheric pressure surrounding the jet nozzle was measured by four lip static probes located in the exhaust portion of the chamber (station 0).

Fuel flow was measured by two rotameters connected in series and calibration of the rotameters was made with the type fuel used in this investigation (MIL-F-5624A, grade JP-4).

# PROCEDURE

The inlet conditions were varied to correspond to Reynolds number indices from 0.15 to 0.80. For each inlet condition, the exhaust pressure was reduced to the minimum of the exhaust system with the engine operating at rated speed. The inlet temperature and pressure and the exhaust pressure were then maintained constant while data were taken over a range of engine speeds from rated speed to approximately the speed where the exhaust nozzle became unchoked. A summary of the operating conditions covered in this investigation is given in the following table:

| Reynolds number index | Inlet total temperature (°R) | Inlet total pressure (lb/sq ft) | Ram-pressure ratio |
|---|---|---|---|
| 0.15 | 410 | 232 | 1.19 |
| .2 | 410 | 315 | 1.48 |
| .25 | 410 | 387 | 1.64 |
| .3 | 410 | 465 | 1.34 |
| .3 | 410 | 465 | 1.70 |
| .4 | 467 | 739 | 1.35 |
| .425 | 437 | 718 | 1.41 |
| .5 | 467 | 923 | 1.95 |
| .6 | 467 | 1108 | 2.14 |
| .8 | 530 | 1740 | 1.70 |

The methods of calculation are given in the appendix.

## PRESENTATION OF DATA

The simulated altitude performance data obtained in this investigation were corrected to NACA standard altitude conditions and are presented in table I. Generalization of data for various engine-inlet conditions corresponding to a given Reynolds number index requires that 2625
critical flow be established in the exhaust nozzle. The range of corrected engine speeds over which the exhaust nozzle of the engine was choked is shown in figure 3 for a range of Reynolds number indices corresponding to various altitudes and flight Mach numbers. At all altitudes, this minimum corrected engine speed at which choking occurred decreased approximately linearly from about 7600 rpm at a flight Mach number of 0.2 to about 5750 rpm at a flight Mach number of 1.10. The data of this report may be used to determine performance only at flight conditions in the choked region above this curve.

In order to aid in determining the Reynolds number index corresponding to a given flight condition and thereby determine the engine performance at NACA standard altitude conditions from the generalized data presented, the values of $\delta$, $\theta$, $\varphi$, and Reynolds number index are given in table II for a wide range of flight conditions; 100 percent ram-pressure recovery was assumed.

### Effect of Engine-Inlet Conditions on Performance

In addition to the basic engine performance, two effects of special concern regarding exhaust-nozzle sizing and aircraft take-off are the effect of engine-inlet temperature on exhaust-gas temperature at sea-level static-pressure conditions and the effect of engine-inlet ram-pressure ratio on exhaust-gas temperature and thrust at low flight speeds and low altitudes. However, because of test-facility limitations, these effects had to be investigated at altitudes of 15,000 and 20,000 feet, respectively.

The effect of engine-inlet total temperature on exhaust-gas total temperature is presented in figure 4 for a constant actual engine speed of 7950 rpm. A decrease in inlet total temperature from 532° to 465° R resulted in a decrease in exhaust-gas total temperature of approximately 50° R, and any further decrease in inlet temperature caused the exhaust-gas temperature to increase. The data for the performance variables presented in figure 4 along with other engine performance data are included in table III.

The effect of engine-inlet ram-pressure ratio on corrected exhaust-gas total temperature and the corresponding net thrust variation for various corrected engine speeds are shown in figure 5. The decrease in corrected exhaust-gas total temperature as ram-pressure ratio is increased results from an increase in effective flow area of the exhaust nozzle, which corresponds to an increase in nozzle flow coefficient. The change in effective flow area is caused by the fact that the exhaust nozzle is not fully choked and by the existence of a
2625 boundary layer of subsonic flow around the sonic jet. This layer of subsonic flow decreases in depth as the engine-inlet ram-pressure ratio is increased, thus increasing the effective area of the nozzle and reducing the tail-pipe temperature. The effect of this flow-area change becomes constant after a ram-pressure ratio of approximately 1.25 (which corresponds to a tail-pipe pressure ratio of approximately 2.5) is attained. At this ram-pressure ratio of 1.25, the net thrust loss is approximately 3 percent of the thrust that could be obtained if the exhaust-gas total temperature had remained constant at the value obtained for an engine-inlet static condition. A tabulation of these data along with other engine performance parameters is given in table IV.

## General Performance Calibration Data

The effect of Reynolds number index on generalized engine performance is shown in figures 6 to 10 where the corrected air flow, corrected fuel flow, corrected jet thrust parameter, corrected exhaust-gas total temperature, and engine pumping characteristics are presented. The variation of corrected air flow with corrected engine speed for various Reynolds number indices is presented in figure 6. At a corrected engine speed of 7950 rpm, the corrected air flow decreased from 104.0 to 99.2 pounds per second as Reynolds number index was decreased from 0.80 to 0.15. The corrected fuel flow (fig. 7) generalized for Reynolds number indices from 0.80 to 0.30 at corrected engine speeds above about 7500 rpm but increased with a further reduction of Reynolds number index. This increase in fuel flow results from the required rise in turbine-inlet temperature due to the decrease in compressor efficiency and the decrease in combustion efficiency at low Reynolds number indices. The increase in corrected fuel flow at rated corrected engine speed was approximately 8 percent as Reynolds number index was reduced from 0.30 to 0.15. The corrected jet thrust parameter, based on scale thrust readings, (fig. 8) generalized throughout the range of Reynolds number indices and corrected engine speeds investigated. Corrected exhaust-gas total temperature (fig. 9) generalized for Reynolds number indices from 0.80 to 0.30 but increased with a further reduction in Reynolds index. This increase in corrected exhaust-gas total temperature at the lower Reynolds numbers is attributed primarily to the decrease in compressor efficiency, which requires more work from the

turbine to maintain a given engine speed and hence a higher turbine-inlet temperature. Figure 10 illustrates the effect of Reynolds number index on the engine pumping characteristics. The relation between engine total-pressure ratio and engine total-temperature ratio is defined by a single line as Reynolds number index is decreased from 0.80 to 0.30 but shifts in the direction of increased engine total-temperature ratio at a given engine total-pressure ratio for a further reduction in Reynolds number index. This shift in the curves reflects the reduced efficiency of the compressor and turbine at conditions of low inlet Reynolds number. 2625

The corrected engine windmilling speed is shown in figure 11 as a function of flight Mach number for altitudes from 15,000 to 45,000 feet. The corrected engine windmilling speed was unaffected by changes in altitude for the range of flight Mach numbers investigated.

The thrust is dependent upon the exhaust-gas temperature and in this investigation the gas temperatures were measured by the engine manufacturer's four-probe and five-probe thermocouple harnesses as well as the 25 NACA thermocouples. The readings of these different sets of instrumentation differ, with the result that the thrust at a given measured temperature will also vary. A comparison of the thrusts obtained is presented in the following table for NACA standard sea-level static conditions:

| Performance based on | Engine speed (rpm) | Engine manufacturer's exhaust-gas thermocouple reading $T_{9,i}$ (°R) | Exhaust-gas total temperature based on NACA instrumentation $T_9$ (°R) (a) | Thrust (lb) |
|---|---|---|---|---|
| Exhaust-gas total temperature of 1710° R | 7950 | ---- | 1710 | 5894 |
| Engine manufacturer's five-probe thermocouple harness | 7950 | 1710 | 1760 | 6074 |
| Engine manufacturer's four-probe thermocouple harness | 7950 | 1710 | 1766 | 6098 |

[a]Based on an average of 25 NACA thermocouples located 15.15 in. downstream of tail-cone-outlet flange.

The exhaust nozzle (area, 298.5 sq in.) was sized so as to give an exhaust-gas temperature of 1710° R (1250° F) at standard sea-level static conditions and rated engine speed. For this exhaust-gas temperature of 1710° R, the standard sea-level static thrust is 5894 pounds.

Because the engine is normally rated by the manufacturer for an exhaust-gas temperature based on a thermocouple reading obtained from the four- or five-probe thermocouple harness, thrust values have been included in the preceding table for the thermocouple reading of 1710° R obtained from the four- and five-probe systems with the corresponding gas temperatures included. The four- and five-probe harnesses indicated an exhaust-gas temperature between 50° and 60° lower than the true gas temperature and therefore give a correspondingly higher thrust for a
2625 given temperature limit based on a thermocouple reading. The method employed in calculating the thrust values is given in the appendix.

## SUMMARY OF RESULTS

The following results were obtained from an investigation of the altitude performance of a J47-25 turbojet engine in an altitude chamber over a range of engine-inlet Reynolds number indices from 0.15 to 0.80:

1. At a constant engine speed, a decrease in inlet total temperature from 532° to 465° R resulted in a decrease in exhaust-gas total temperature of approximately 50° R.

2. At a given corrected engine speed and with critical pressure ratio existing in the exhaust nozzle, the corrected exhaust-gas temperature decreased as the ram-pressure ratio was increased from 1.0 to 1.25. Further increases in ram-pressure ratio had no effect on temperature. The corresponding net thrust loss at ram-pressure ratios of 1.25 and above, due to the reduction in exhaust-gas temperature below the limiting value, amounted to 3 percent.

3. At a corrected engine speed of 7950 rpm, the corrected air flow decreased from 104.0 to 99.2 pounds per second as Reynolds number index was decreased from 0.80 to 0.15.

4. Corrected exhaust-gas total temperature, corrected fuel flow, and engine pumping characteristics generalized for Reynolds number indices from 0.80 to 0.30 and the corrected jet thrust parameter generalized throughout the range of Reynolds number indices and corrected engine speeds investigated.

5. The corrected engine windmilling speed was unaffected by changes in altitude for the range of flight Mach numbers investigated.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 3, 1952

## APPENDIX - METHODS OF CALCULATION

### Symbols

The following symbols are used in the calculation and on the figures:

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| | |
|---|---|
| $A$ | area, sq ft |
| $C_T$ | thermal expansion coefficient, ratio of hot exhaust-nozzle area to cold exhaust-nozzle area |
| $C_d$ | ratio of effective flow area to physical flow area |
| $C_j$ | jet thrust coefficient |
| $F_d$ | thrust system scale reading, lb |
| $F_j$ | jet thrust, lb |
| $F_n$ | net thrust, lb |
| $f/a$ | fuel-air ratio |
| $g$ | acceleration due to gravity, 32.2 ft/sec$^2$ |
| $M$ | Mach number |
| $N$ | engine speed, rpm |
| $P$ | total pressure, lb/sq ft absolute |
| $p$ | static pressure, lb/sq ft absolute |
| $R$ | gas constant, 53.3 ft-lb/(lb)($^{\circ}$R) |
| $Re$ | Reynolds number index, $\frac{\delta_1}{\varphi_1 \sqrt{\theta_1}}$ |
| $T$ | total temperature, $^{\circ}$R |
| $T_i$ | indicated total temperature, $^{\circ}$R |
| $V$ | velocity, ft/sec |
| $W_a$ | air flow, lb/sec |

$W_f$ fuel flow, lb/hr

$W_g$ gas flow, lb/sec

$\gamma$ ratio of specific heats

$\delta$ ratio of engine-inlet total pressure $P_1$ to NACA standard sea-level pressure, 2116 lb/sq ft

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$\theta$ ratio of engine-inlet total temperature $T_1$ to NACA standard sea-level temperature, 519° R

$\varphi$ ratio of coefficient of viscosity corresponding with $T_1$ to coefficient of viscosity corresponding with NACA standard sea-level temperature, 519° R

Subscripts:

0 free-stream conditions

0a bellmouth inlet

1 engine inlet

2 compressor inlet

3 compressor outlet

5 turbine outlet

9 exhaust-nozzle inlet

10 exhaust-nozzle outlet

cl compressor 12-stage leakage air flow

d thrust-cell measurement

e equivalent

i indicated

n vena contracta at exhaust-nozzle outlet

r rake

s scale

## Calculations

Flight Mach number and velocity. - The flight Mach number assuming complete ram-pressure recovery was computed as

$$M_0 = \sqrt{\frac{2}{\gamma_1 - 1}\left[\left(\frac{P_1}{p_0}\right)^{\frac{\gamma_1 - 1}{\gamma_1}} - 1\right]} \qquad (1)$$

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and

$$V_0 = M_0 \sqrt{\gamma_1 g R T_1 \left(\frac{p_0}{P_1}\right)^{\frac{\gamma_1 - 1}{\gamma_1}}}$$

Temperature. - Total temperature was determined by a calibrated thermocouple with an impact-recovery factor of 0.85 from the indicated temperature by the following equation:

$$T = \frac{T_i \left(\frac{P}{p}\right)^{\frac{\gamma - 1}{\gamma}}}{1 + 0.85\left[\left(\frac{P}{p}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right]} \qquad (2)$$

Engine air flow. - Because of the large amount of air-flow leakage at the station where the engine inlet screens are mounted, the gas flow was determined at the exhaust-nozzle exit from total pressure and temperature at the nozzle inlet (station 9) by the following equation with the assumption that no energy loss occurred between the nozzle inlet and exit:

$$W_{g,n} = C_T\, C_d\, A_{10}\, p_n \sqrt{\frac{2\,\gamma_9}{\gamma_9 - 1}\,\frac{g}{RT_9}\left[\left(\frac{P_9}{p_n}\right)^{\frac{\gamma_9 - 1}{\gamma_9}} - 1\right]\left(\frac{P_9}{p_n}\right)^{\frac{\gamma_9 - 1}{\gamma_9}}} \qquad (3)$$

where in the subsonic case

$$p_n = p_0$$

and in the choked case

$$p_n = \frac{P_9}{\left(\frac{1 + \gamma_9}{2}\right)^{\frac{\gamma_9}{\gamma_9 - 1}}}$$

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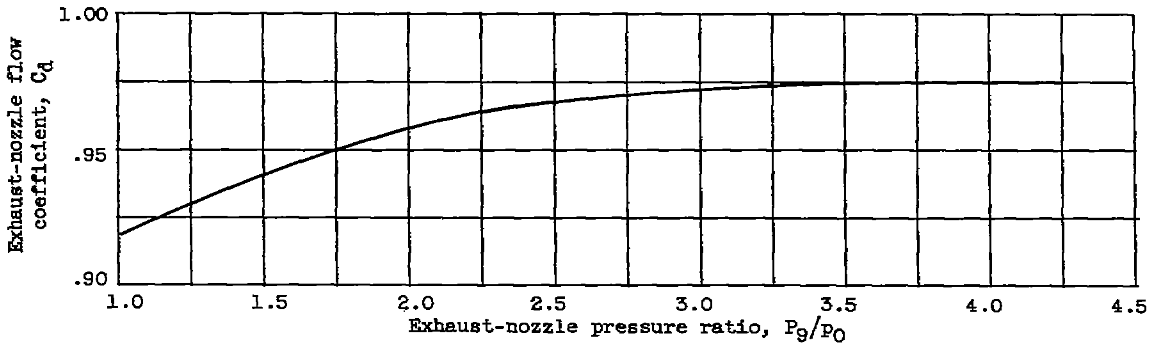
The value of the flow coefficient was determined from reference 2 using the area ratio and cone angle of the particular nozzle employed in this investigation. The magnitude of the flow coefficient is presented in the following curve:




The compressor-inlet air flow was then determined from the nozzle gas flow by

$$W_{a,2} = W_{g,n} - W_{f,e} + W_{a,cl} \tag{4}$$

where the compressor leakage air flow $W_{a,cl}$ was measured at two instrumented mid-frame bleed ports.

The engine-inlet air flow $W_{a,1}$ based on pressure and temperature measurements in a bellmouth mounted on the front of the engine was determined by the same general equation as for the tail-pipe gas flow. The percentage of leakage at the section housing the inlet screens is

$$W_{a,1-2} = \frac{W_{a,1} - W_{a,2}}{W_{a,2}}$$

and was 3.3 percent of the compressor-inlet air flow $W_{a,2}$ for the range of conditions covered in this investigation.

Thrusts. - The jet thrust as determined from the thrust system measurements was calculated from the equation

$$F_{j,s} = F_d + (A_{seal} - A_9)(P_1 - p_{seal}) + A_9(P_1 - p_0) + 0.80\left(\frac{1}{2}\frac{W_{a,1}}{g}V_{0a}\right) \tag{5}$$

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where the last term is the momentum force existing at the bellmouth inlet which was experimentally determined by instrumentation located on the surfaces of the bellmouth and bullet along with instrumentation at station 1. The net thrust will be determined by subtracting the equivalent momentum of the air at the engine inlet from the jet thrust.

$$F_{n,s} = F_{j,s} - \frac{W_{a,1}V_0}{g} = F_{j,s} - \frac{(W_{a,2} + W_{a,1-2})V_0}{g} \tag{6}$$

Jet thrust coefficient. - The jet thrust coefficient is defined as the ratio of scale jet thrust to rake jet thrust:

$$C_j = \frac{F_{j,s}}{F_{j,r}} \tag{7}$$

where

$$F_{j,r} = \frac{W_{g,n}}{g}V_n + A_n(p_n - p_0) \tag{8}$$

The charts in reference 3 were used in the solution of the preceding equation. When all the data obtained in this investigation were employed, the jet thrust coefficient was found to be independent of exhaust-nozzle pressure ratio and was a constant value of 0.99. The scatter in the coefficient values was approximately ±1 percent for the range of conditions investigated.

Determination of performance for particular flight condition. - For a given flight condition, values of Re, $\delta$, and $\theta$ can be obtained from table II. If these generalizing parameter values and engine speed are known, air flow, fuel flow, and exhaust-gas temperature can be obtained from the various performance curves. In order to determine

the net thrust, the jet thrust parameter must first be corrected to the desired flight condition to obtain the jet thrust. Then in order to obtain net thrust, the leakage between stations 1 and 2 must be added to the air flow for station 2 so that

$$F_n = F_j - \left(\frac{W_{a,2} + W_{a,1-2}}{g}\right) V_0$$

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Sea-level static thrust ratings. - Because of the effect of inlet ram pressure on exhaust-gas temperature, data taken at an altitude of 5000 feet and flight Mach number of 0.2, which are included in the following table, had to be corrected to sea-level static conditions in order to determine the sea-level thrust for the engine.

| Engine-inlet total pressure $P_1$ (lb/sq ft abs) | Engine-inlet total temperature $T_1$ (°R) | Nozzle-inlet total pressure $P_9$ (lb/sq ft abs) | Nozzle-inlet total temperature $T_9$ (°R) | Engine manufacturer's 4-probe nozzle-inlet indicated temperature $T_{9,i}$ (°R) | Engine manufacturer's 5-probe nozzle-inlet indicated temperature $T_{9,i}$ (°R) | Corrected engine speed $N/\sqrt{\theta_1}$ (rpm) | Corrected compressor-inlet air flow $W_{a,2}\sqrt{\theta_1}/\delta_1$ (lb/sec) | Corrected compressor leakage air flow $W_{c1}\sqrt{\theta_1}/\delta_1$ (lb/sec) | Corrected engine fuel flow $\frac{W_{f,2}}{\delta_1\sqrt{\theta_1}}$ (lb/hr) |
|---|---|---|---|---|---|---|---|---|---|
| 1812 | 537 | 3050 | 1568 | 1522 | 1519 | 7281 | 95.7 | 1.9 | 4681 |
| 1814 | 537 | 3145 | 1612 | 1560 | 1560 | 7443 | 95.6 | 1.9 | 5008 |
| 1813 | 534 | 3154 | 1601 | 1556 | 1553 | 7464 | 96.6 | 2.0 | 5014 |
| 1812 | 537 | 3233 | 1656 | 1601 | 1604 | 7594 | 99.4 | 2.0 | 5348 |
| 1816 | 537 | 3370 | 1728 | 1674 | 1678 | 7813 | 101.8 | 2.0 | 5870 |
| 1813 | 537 | 3366 | 1731 | 1672 | 1680 | 7816 | 101.2 | 2.0 | 5916 |
| 1814 | 533 | 3397 | 1736 | 1679 | 1685 | 7846 | 102.1 | 2.0 | 6022 |

For sea-level static engine-inlet conditions, an engine speed of 7950 rpm, and a given exhaust-gas temperature, the tail-pipe total pressure may be determined from the engine-pumping-characteristic curves; therefore, the pressure ratio across the exhaust nozzle may also be determined. A plot of corrected fuel flow against engine temperature ratio will give the fuel flow for the proper exhaust-gas temperature. The compressor-inlet air flow may be determined from a plot of corrected air flow against corrected engine speed. In order to determine tail-pipe gas flow, compressor leakage air flow must be deducted and fuel flow added to the inlet air flow. From fuel flow, air flow, and exhaust-gas temperature, a value for $\gamma_9$ may be obtained. All the factors that are required to calculate the rake jet thrust from equation (8) are now known. To the rake jet thrust there must be applied a jet thrust coefficient obtained from the value presented in this appendix in order to obtain the final sea-level jet thrust value.

The preceding sea-level static thrust calcualtion required the use of two assumptions:

(1) The required nozzle-area change for the range of exhaust-gas temperatures of interest has no effect on the engine pumping characteristics.

(2) The required nozzle-area change for the small change in exhaust-gas temperature has no effect on the curve of corrected air flow against corrected engine speed. Both of these assumptions were checked with data that were obtained during this investigation and verified as accurate and logical assumptions.

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2. Grey, Ralph E., Jr., and Wilstead, H. Dean: Performance of Conical Jet Nozzles in Terms of Flow and Velocity Coefficients. NACA Rep. 933, 1949. (Supersedes NACA TN 1757.)

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TABLE I. - STANDARD

| Reynolds number index Re | Engine speed N (rpm) | Altitude static pressure $p_0$ (lb/sq ft abs) | Engine-inlet total pressure $P_1$ (lb/sq ft abs) | Ram-pressure ratio $P_1/p_0$ | Engine-inlet total temperature $T_1$ (°R) | Compressor-outlet total pressure $P_3$ (lb/sq ft abs) | Compressor-outlet total temperature $T_3$ (°R) | Turbine-inlet total pressure, $P_4$ (lb/sq ft abs) | Turbine-outlet total pressure, $P_5$ (lb/sq ft abs) | Turbine-outlet total temperature, $T_5$ (°R) | Nozzle-inlet total pressure, $P_8$ (lb/sq ft abs) | Nozzle-inlet static pressure, $p_8$ (lb/sq ft abs) | Nozzle-inlet total temperature, $T_9$ (°R) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.147 | 5953 | 205 | 232 | 1.132 | 415 | 902 | 661 | 860 | 346 | 1128 | 333 | 263 | 1102 |
| .151 | 6362 | 206 | 238 | 1.154 | 415 | 1058 | 695 | 1008 | 393 | 1234 | 376 | 292 | 1209 |
| .156 | 7193 | 203 | 246 | 1.209 | 415 | 1335 | 761 | 1267 | 490 | 1481 | 468 | 364 | 1477 |
| .154 | 7409 | 201 | 241 | 1.199 | 414 | 1358 | 780 | 1292 | 504 | 1570 | 481 | 372 | 1563 |
| .151 | 7578 | 196 | 237 | 1.205 | 414 | 1385 | 800 | 1319 | 516 | 1662 | 492 | 381 | 1632 |
| .150 | 7707 | 192 | 235 | 1.221 | 413 | 1412 | 810 | 1344 | 528 | 1721 | 504 | 390 | 1729 |
| .202 | 5927 | 218 | 315 | 1.449 | 412 | 1211 | 650 | 1152 | 443 | 1035 | 427 | 327 | 1007 |
| .200 | 6362 | 215 | 313 | 1.457 | 413 | 1403 | 684 | 1337 | 513 | 1164 | 491 | 378 | 1162 |
| .201 | 6801 | 212 | 313 | 1.475 | 412 | 1582 | 718 | 1501 | 577 | 1296 | 555 | 427 | 1300 |
| .202 | 7205 | 211 | 316 | 1.497 | 412 | 1713 | 753 | 1626 | 631 | 1442 | 604 | 466 | 1442 |
| .200 | 7407 | 209 | 313 | 1.499 | 412 | 1780 | 772 | 1692 | 655 | 1521 | 627 | 484 | 1531 |
| .199 | 7574 | 206 | 311 | 1.513 | 413 | 1829 | 781 | 1743 | 675 | 1606 | 646 | 501 | 1602 |
| .196 | 7726 | 210 | 311 | 1.482 | 414 | 1899 | 807 | 1807 | 702 | 1686 | 671 | 521 | 1684 |
| .249 | 5921 | 241 | 392 | 1.622 | 414 | 1483 | 647 | 1409 | 543 | 996 | 523 | 400 | 992 |
| .248 | 6358 | 238 | 389 | 1.634 | 414 | 1724 | 682 | 1644 | 632 | 1130 | 608 | 468 | 1138 |
| .248 | 6815 | 237 | 389 | 1.642 | 414 | 1958 | 718 | 1860 | 714 | 1270 | 686 | 527 | 1279 |
| .250 | 7207 | 238 | 391 | 1.642 | 413 | 2118 | 750 | 2010 | 777 | 1420 | 745 | 576 | 1418 |
| .247 | 7409 | 238 | 389 | 1.632 | 414 | 2189 | 770 | 2081 | 805 | 1490 | 772 | 597 | 1487 |
| .249 | 7570 | 237 | 389 | 1.639 | 413 | 2276 | 787 | 2167 | 837 | 1564 | 802 | 619 | 1571 |
| .248 | 7818 | 239 | 386 | 1.619 | 413 | 2349 | 814 | 2238 | 871 | 1686 | 834 | 648 | 1707 |
| .299 | 5932 | 367 | 470 | 1.280 | 414 | 1817 | 652 | 1727 | 675 | 1006 | 650 | 506 | 1011 |
| .296 | 6358 | 354 | 468 | 1.323 | 416 | 2091 | 684 | 1994 | 764 | 1117 | 735 | 566 | 1128 |
| .302 | 6360 | 273 | 473 | 1.732 | 413 | 2092 | 679 | 1995 | 764 | 1111 | 735 | 567 | 1122 |
| .296 | 6815 | 351 | 468 | 1.333 | 416 | 2335 | 719 | 2218 | 854 | 1253 | 819 | 631 | 1271 |
| .311 | 6822 | 280 | 486 | 1.738 | 412 | 2446 | 715 | 2324 | 890 | 1248 | 855 | 659 | 1268 |
| .303 | 7193 | 277 | 475 | 1.711 | 412 | 2561 | 746 | 2431 | 936 | 1379 | 899 | 698 | 1398 |
| .297 | 7195 | 344 | 468 | 1.360 | 415 | 2523 | 752 | 2395 | 926 | 1388 | 888 | 688 | 1400 |
| .298 | 7407 | 338 | 466 | 1.377 | 413 | 2622 | 770 | 2494 | 965 | 1480 | 926 | 716 | 1484 |
| .300 | 7415 | 278 | 469 | 1.686 | 412 | 2651 | 766 | 2521 | 974 | 1471 | 934 | 724 | 1488 |
| .297 | 7570 | 338 | 466 | 1.380 | 413 | 2699 | 786 | 2571 | 995 | 1542 | 954 | 737 | 1557 |
| .303 | 7574 | 276 | 473 | 1.712 | 412 | 2755 | 784 | 2624 | 1024 | 1553 | 981 | 759 | 1570 |
| .302 | 7725 | 279 | 469 | 1.681 | 411 | 2818 | 800 | 2685 | 1054 | 1630 | 1009 | 782 | 1652 |
| .401 | 5923 | 553 | 740 | 1.338 | 467 | 2481 | 699 | 2345 | 918 | 998 | 886 | 702 | 1003 |
| .404 | 6360 | 555 | 743 | 1.339 | 466 | 2919 | 733 | 2775 | 1072 | 1116 | 1030 | 800 | 1135 |
| .401 | 6813 | 555 | 744 | 1.340 | 469 | 3349 | 774 | 3194 | 1233 | 1263 | 1182 | 911 | 1294 |
| .405 | 7198 | 547 | 739 | 1.351 | 464 | 3699 | 800 | 3516 | 1356 | 1381 | 1302 | 1006 | 1413 |
| .397 | 7405 | 558 | 737 | 1.320 | 470 | 3834 | 824 | 3638 | 1403 | 1459 | 1347 | 1043 | 1495 |
| .404 | 7570 | 554 | 747 | 1.349 | 468 | 3973 | 840 | 3769 | 1468 | 1521 | 1410 | 1090 | 1555 |
| .399 | 7947 | 549 | 741 | 1.349 | 470 | 4258 | 878 | 4056 | 1580 | 1706 | 1521 | 1176 | 1732 |
| .406 | 7956 | 552 | 746 | 1.350 | 466 | 4285 | 874 | 4089 | 1580 | 1706 | 1523 | 1184 | 1748 |
| .434 | 5930 | 506 | 718 | 1.418 | 430 | 2619 | 663 | 2483 | 958 | 969 | 922 | 719 | 979 |
| .431 | 6362 | 508 | 721 | 1.420 | 434 | 3013 | 703 | 2869 | 1106 | 1100 | 1062 | 819 | 1116 |
| .419 | 6817 | 505 | 719 | 1.425 | 443 | 3371 | 746 | 3216 | 1240 | 1242 | 1189 | 918 | 1268 |
| .431 | 7112 | 507 | 725 | 1.429 | 436 | 3728 | 763 | 3539 | 1357 | 1336 | 1302 | 1006 | 1369 |
| .425 | 7407 | 509 | 720 | 1.416 | 438 | 3925 | 792 | 3728 | 1435 | 1444 | 1380 | 1065 | 1475 |
| .419 | 7565 | 510 | 720 | 1.412 | 443 | 3998 | 812 | 3801 | 1469 | 1512 | 1415 | 1095 | 1541 |
| .428 | 7741 | 511 | 728 | 1.424 | 441 | 4137 | 830 | 3937 | 1524 | 1591 | 1468 | 1138 | 1622 |
| .419 | 7962 | 511 | 710 | 1.391 | 438 | 4251 | 849 | 4052 | 1585 | 1702 | 1527 | 1189 | 1735 |
| .510 | 5929 | 482 | 940 | 1.951 | 467 | 3085 | 696 | 2907 | 1106 | 928 | 1080 | 816 | 940 |
| .509 | 6362 | 478 | 944 | 1.977 | 469 | 3629 | 735 | 3442 | 1317 | 1081 | 1262 | 972 | 1106 |
| .509 | 6817 | 480 | 939 | 1.956 | 467 | 4201 | 770 | 4006 | 1537 | 1234 | 1475 | 1137 | 1271 |
| .508 | 7193 | 482 | 940 | 1.951 | 468 | 4609 | 801 | 4387 | 1689 | 1347 | 1624 | 1252 | 1399 |
| .508 | 7409 | 474 | 939 | 1.983 | 468 | 4750 | 818 | 4504 | 1776 | 1417 | 1699 | 1312 | 1469 |
| .508 | 7566 | 481 | 942 | 1.961 | 469 | 4985 | 835 | 4730 | 1829 | 1489 | 1759 | 1363 | 1537 |
| .502 | 7718 | 477 | 931 | 1.952 | 469 | 5073 | 851 | 4818 | 1862 | 1557 | 1784 | 1391 | 1602 |
| .509 | 7722 | 485 | 939 | 1.936 | 467 | 5138 | 848 | 4880 | 1887 | 1551 | 1818 | 1408 | 1600 |
| .503 | 7943 | 481 | 930 | 1.936 | 468 | 5268 | 872 | 5011 | 1948 | 1666 | 1873 | 1457 | 1711 |
| .505 | 7953 | 482 | 940 | 1.951 | 471 | 5320 | 875 | 5062 | 1960 | 1666 | 1891 | 1467 | 1711 |
| .610 | 5930 | 520 | 1127 | 2.166 | 468 | 3663 | 697 | 3442 | 1311 | 916 | 1256 | 966 | 931 |
| .613 | 6362 | 519 | 1121 | 2.161 | 464 | 4352 | 730 | 4128 | 1582 | 1065 | 1514 | 1166 | 1097 |
| .610 | 6813 | 520 | 1123 | 2.159 | 467 | 5008 | 769 | 4773 | 1851 | 1220 | 1759 | 1326 | 1258 |
| .605 | 7193 | 526 | 1124 | 2.138 | 470 | 5492 | 802 | 5229 | 2016 | 1345 | 1955 | 1498 | 1393 |
| .608 | 7411 | 520 | 1118 | 2.148 | 466 | 5764 | 816 | 5470 | 2107 | 1511 | 2031 | 1571 | 1466 |
| .609 | 7578 | 524 | 1123 | 2.142 | 467 | 5981 | 831 | 5675 | 2190 | 1477 | 2111 | 1635 | 1526 |
| .602 | 7722 | 528 | 1125 | 2.140 | 472 | 6122 | 852 | 5812 | 2245 | 1543 | 2167 | 1677 | 1591 |
| .607 | 7949 | 530 | 1131 | 2.134 | 471 | 6419 | 874 | 6107 | 2369 | 1648 | 2288 | 1775 | 1708 |
| .596 | 7951 | 520 | 1114 | 2.144 | 472 | 6302 | 875 | 5994 | 2320 | 1655 | 2240 | 1740 | 1712 |
| .809 | 5929 | 1060 | 1789 | 1.688 | 537 | 4913 | 760 | 4608 | 1788 | 924 | 1729 | 1368 | 934 |
| .807 | 6372 | 1050 | 1788 | 1.703 | 538 | 5884 | 801 | 5567 | 2134 | 1076 | 2047 | 1587 | 1086 |
| .807 | 6817 | 1050 | 1785 | 1.700 | 537 | 6894 | 841 | 6562 | 2523 | 1234 | [illegible] | [illegible] | 1268 |
| .809 | 7197 | 1050 | 1790 | 1.705 | 537 | 7732 | 874 | 7392 | 2845 | 1377 | 2735 | 2111 | 1419 |
| .809 | 7409 | 1047 | 1789 | 1.709 | 537 | 8153 | 892 | 7807 | 3013 | 1450 | 2897 | 2241 | 1498 |
| .807 | 7568 | 1050 | 1786 | 1.701 | 537 | 8449 | 905 | 8098 | 3128 | 1497 | 3008 | 2351 | 1549 |
| .809 | 7727 | 1053 | 1788 | 1.698 | 537 | 8763 | 918 | 8389 | 3249 | 1566 | 3123 | 2421 | 1612 |
| .803 | 7951 | 1034 | 1779 | 1.721 | 538 | 9155 | 939 | 8744 | 3385 | 1669 | 3261 | 2533 | 1701 |

NACA

ENGINE PERFORMANCE DATA

| Air frame mfg. 4-probe nozzle-inlet total pressure, $P_9$ (lb/sq ft abs) | Air frame mfg. 5-probe nozzle-inlet total pressure, $P_9$ (lb/sq ft abs) | Engine mfg. 4-probe nozzle-inlet indicated temperature $T_{9,i}$, (°R) | Engine mfg. 5-probe nozzle-inlet indicated temperature, $T_{9,i}$ (°R) | Compressor-inlet air flow, $W_{a,2}$ (lb/sec) | Engine fuel flow, $W_{f,e}$ (lb/hr) | Fuel-air ratio f/a | Jet thrust $F_j$ (lb) | Net thrust $F_n$ (lb) | Corrected engine speed $N/\sqrt{\theta_1}$ (rpm) | Corrected compressor-inlet air flow $W_{a,2}\sqrt{\theta_1}/\delta_1$ (lb/sec) | Corrected engine fuel flow $W_{f,e}/\delta_1\sqrt{\theta_1}$ (lb/hr) | Corrected exhaust-gas total temperature, $T_9/\theta_1$ (°R) | Corrected jet thrust parameter $(F_j+p_0A_n)/\delta_1$ (lb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 340 | 336 | 1057 | 1058 | 10.3 | 374 | 0.0103 | 391 | 258 | 6655 | 83.7 | 3815 | 1379 | 7450 |
| 382 | 382 | 1188 | 1197 | 11.4 | 462 | .0115 | 519 | 357 | 7115 | 90.5 | 4598 | 1512 | 8420 |
| 471 | 477 | 1427 | 1446 | 12.9 | 696 | .0153 | 753 | 542 | 8042 | 99.4 | 6696 | 1848 | 10,950 |
| 482 | 489 | 1512 | 1521 | 12.9 | 762 | .0168 | 801 | 596 | 8298 | 101.2 | 7484 | 1980 | 10,690 |
| 493 | 498 | 1582 | 1590 | 12.9 | 822 | .0181 | 817 | 611 | 8487 | 103.1 | 8233 | 2055 | 10,110 |
| 505 | 508 | 1668 | 1670 | 12.9 | 883 | .0195 | 888 | 677 | 8640 | 103.5 | 8931 | 2173 | 11,600 |
| 437 | 432 | 981 | 986 | 14.2 | 438 | .0087 | 603 | 281 | 6650 | 85.1 | 3299 | 1269 | 7080 |
| 498 | 499 | 1124 | 1132 | 15.3 | 575 | .0106 | 791 | 437 | 7132 | 92.4 | 4357 | 1461 | 8360 |
| 560 | 566 | 1285 | 1274 | 16.4 | 730 | .0126 | 968 | 588 | 7631 | 98.9 | 5532 | 1638 | 9520 |
| 607 | 615 | 1395 | 1405 | 17.0 | 883 | .0147 | 1105 | 704 | 8084 | 101.6 | 6641 | 1817 | 10,340 |
| 628 | 637 | 1471 | 1478 | 17.1 | 973 | .0161 | 1165 | 765 | 8311 | 103.1 | 7388 | 1929 | 10,810 |
| 647 | 653 | 1551 | 1558 | 17.2 | 1059 | .0175 | 1227 | 819 | 8490 | 104.4 | 8067 | 2014 | 11,240 |
| 672 | 676 | 1636 | 1639 | 17.4 | 1156 | .0189 | 1262 | 862 | 8652 | 105.6 | 8798 | 2124 | 11,540 |
| 535 | 529 | 964 | 967 | 17.7 | 516 | .0082 | 829 | 371 | 6632 | 85.3 | 3124 | 1244 | 7190 |
| 615 | 617 | 1105 | 1111 | 19.3 | 687 | .0101 | 1049 | 561 | 7121 | 93.6 | 4186 | 1427 | 8390 |
| 692 | 699 | 1240 | 1244 | 20.5 | 883 | .0122 | 1246 | 713 | 7653 | 99.5 | 5374 | 1604 | 9440 |
| 747 | 758 | 1369 | 1375 | 21.1 | 1062 | .0142 | 1398 | 848 | 8079 | 102.1 | 6448 | 1782 | 10,250 |
| 772 | 783 | 1446 | 1455 | 21.3 | 1161 | .0154 | 1459 | 919 | 8298 | 103.8 | 7083 | 1877 | 10,690 |
| 801 | 813 | 1513 | 1524 | 21.6 | 1255 | .0165 | 1544 | 985 | 8486 | 105.0 | 7653 | 1975 | 11,080 |
| 832 | 841 | 1640 | 1648 | 21.6 | 1402 | .0185 | 1629 | 1078 | 8784 | 105.2 | 8583 | 2146 | 11,610 |
| 661 | 661 | 974 | 982 | 21.4 | 628 | .0083 | 849 | 445 | 6644 | 86.1 | 3167 | 1288 | 7250 |
| 744 | 748 | 1097 | 1104 | 23.2 | 820 | .0100 | 1087 | 628 | 7102 | 93.8 | 4142 | 1408 | 8240 |
| 743 | 747 | 1088 | 1094 | 23.5 | 814 | .0098 | 1281 | 659 | 7130 | 93.6 | 4082 | 1410 | 8270 |
| 826 | 835 | 1233 | 1239 | 24.4 | 1038 | .0120 | 1372 | 873 | 7612 | 98.9 | 5243 | 1586 | 9500 |
| 861 | 871 | 1227 | 1233 | 25.7 | 1074 | .0118 | 1578 | 871 | 7654 | 99.8 | 5247 | 1598 | 9400 |
| 901 | 914 | 1358 | 1360 | 25.7 | 1285 | .0139 | 1736 | 1044 | 8071 | 102.5 | 6546 | 1761 | 10,330 |
| 890 | 902 | 1359 | 1362 | 25.3 | 1246 | .0140 | 1539 | 1011 | 8044 | 102.2 | 6294 | 1751 | 10,180 |
| 925 | 939 | 1438 | 1444 | 25.6 | 1378 | .0152 | 1670 | 1122 | 8303 | 103.9 | 7008 | 1865 | 10,780 |
| 935 | 948 | 1437 | 1447 | 25.9 | 1388 | .0152 | 1830 | 1141 | 8320 | 104.3 | 7033 | 1872 | 10,870 |
| 954 | 966 | 1508 | 1514 | 25.8 | 1463 | .0161 | 1720 | 1175 | 8486 | 104.6 | 74[illegible] | 1957 | 11,000 |
| 981 | 993 | 1519 | 1523 | 26.4 | 1524 | .0165 | 1960 | 1253 | 8498 | 105.3 | 76[illegible] | 1978 | 11,340 |
| 1008 | 1018 | 1597 | 1602 | 26.6 | 1647 | .0176 | 1973 | 1278 | 8685 | 106.7 | 8351 | 2086 | 11,510 |
| 895 | 901 | 969 | 977 | 28.7 | 766 | .0075 | 1067 | 459 | 6243 | 77.8 | 2309 | 1114 | 6330 |
| 1037 | 1049 | 1102 | 1107 | 32.2 | 1062 | .0085 | 1469 | 766 | 6710 | 87.1 | 3193 | 1264 | 7460 |
| 1188 | 1197 | 1256 | 1258 | 34.9 | 1395 | .0114 | 1858 | 1098 | 7167 | 94.3 | 4172 | 1432 | 8560 |
| 1305 | 1315 | 1371 | 1372 | 36.9 | 1708 | .0130 | 2185 | 1374 | 7617 | 99.8 | 5172 | 1581 | 9500 |
| 1348 | 1358 | 1450 | 1448 | 37.1 | 1872 | .0144 | 2248 | 1465 | 7785 | 101.2 | 5847 | 1650 | 9780 |
| 1409 | 1419 | 1508 | 1505 | 38.1 | 2049 | .0153 | 2447 | 1610 | 7971 | 102.5 | 8115 | 1724 | 10,190 |
| 1518 | 1522 | 1679 | 1678 | 38.9 | 2480 | .0182 | 2705 | 1862 | 8352 | 105.8 | 7444 | 1912 | 10,980 |
| 1523 | 1526 | 1698 | 1691 | 38.8 | 2480 | .0182 | 2743 | 1895 | 8394 | 104.4 | 7425 | 1947 | 11,030 |
| 933 | 941 | 950 | 957 | 31.0 | 838 | .0076 | 1276 | 568 | 6517 | 83.2 | 2716 | 1182 | 6860 |
| 1086 | 1084 | 1084 | 1086 | 33.7 | 1116 | .0094 | 1631 | 856 | 6960 | 90.1 | 3582 | 1335 | 7880 |
| 1191 | 1208 | 1231 | 1231 | 35.6 | 1418 | .0113 | 1992 | 1184 | 7383 | 96.6 | 4516 | 1486 | 8940 |
| 1303 | 1318 | 1331 | 1329 | 37.6 | 1700 | .0128 | 2279 | 1412 | 7759 | 100.5 | 5418 | 1629 | 9730 |
| 1378 | 1394 | 1431 | 1431 | 38.3 | 1944 | .0144 | 2478 | 1610 | 8066 | 103.4 | 6219 | 1748 | 10,390 |
| 1414 | 1427 | 1496 | 1498 | 38.5 | 2082 | .0154 | 2557 | 1689 | 8193 | 104.4 | 6631 | 1806 | 10,650 |
| 1464 | 1479 | 1570 | 1575 | 38.9 | 2268 | .0166 | 2697 | 1798 | 8399 | 104.3 | 7153 | 1909 | 10,920 |
| 1522 | 1533 | 1678 | 1682 | 39.1 | 2555 | .0186 | 2809 | 1959 | 8671 | 107.0 | 8294 | [illegible] | 11,530 |
| 1075 | 1083 | 911 | 917 | 37.0 | 858 | .0066 | 1702 | 508 | 6249 | 79.0 | 2036 | 1044 | 6080 |
| 1272 | 1286 | 1079 | 1080 | 40.8 | 1218 | .0087 | 2231 | 898 | 6893 | 86.8 | 2842 | 1224 | 7220 |
| 1478 | 1495 | 1240 | 1236 | 44.5 | 1708 | .0109 | 2779 | 1341 | 7185 | 95.2 | 4056 | 1412 | 8510 |
| 1625 | 1640 | 1362 | 1356 | 46.8 | 2098 | .0127 | 3169 | 1675 | 7574 | 100.0 | 4975 | 1551 | 9386 |
| 1699 | 1714 | 1424 | 1422 | 47.7 | 2317 | .0158 | 3385 | 1842 | 7802 | 102.1 | 5497 | 1629 | 9840 |
| 1758 | 1772 | 1491 | 1490 | 48.3 | 2513 | .0148 | 3540 | 1987 | 7959 | 103.0 | 5935 | 1701 | 10,190 |
| 1793 | 1805 | 1555 | 1555 | 48.2 | 2681 | .0158 | 3618 | 2081 | 8119 | 104.[illegible] | 6411 | 1775 | 10,470 |
| 1815 | 1828 | 1550 | 1551 | 48.9 | 2722 | .0158 | 3644 | 2096 | 8139 | 104.6 | 6467 | 1778 | 10,480 |
| 1871 | 1881 | 1659 | 1661 | 48.6 | 3015 | .0177 | 3819 | 2273 | 8364 | 105.1 | 7[illegible] | 1897 | 10,960 |
| 1889 | 1897 | 1659 | 1660 | 49.1 | 3032 | .0176 | 3861 | 2289 | 8351 | 105.3 | 7163 | 1886 | 10,940 |
| 1275 | 1283 | 901 | 907 | 44.2 | 982 | .0063 | 2119 | 577 | 6214 | 78.8 | 194[illegible] | 103[illegible] | 6010 |
| 1525 | 1544 | 1069 | 1069 | 49.2 | 1455 | .0084 | 2796 | 1103 | 6725 | 87.9 | 2904 | 1226 | 7510 |
| 1760 | 1783 | 1231 | 1227 | 53.5 | 2009 | .0107 | 3466 | 1642 | 7188 | 95.5 | 3993 | 1399 | 8560 |
| 1939 | 1956 | 1357 | 1353 | 56.5 | 2480 | .0125 | 3901 | 1994 | 7560 | 101.[illegible] | 4908 | 1539 | 9400 |
| 2028 | 2042 | 1424 | 1422 | 57.2 | 2765 | .0138 | 4127 | 2187 | 7819 | 102.6 | 5522 | 1633 | 9860 |
| 2112 | 2125 | 1483 | 1481 | 58.2 | 3005 | .0147 | 4549 | 2382 | 7987 | 104.0 | 5967 | 1694 | 10,240 |
| 2164 | 2171 | 1546 | 1544 | 58.4 | 3217 | .0157 | 4472 | 2497 | 8100 | 104.8 | 6348 | 1753 | 10,460 |
| 2280 | 2290 | 1659 | 1656 | 59.5 | 3656 | .0175 | 4773 | 2765 | 8346 | 106.1 | 718[illegible] | 1882 | 10,980 |
| 2238 | 2243 | 1663 | 1659 | 58.2 | 3593 | .0176 | 4697 | 2726 | 8341 | 105.4 | 7157 | 1883 | 10,970 |
| 1748 | 1755 | 899 | 907 | 58.7 | 1102 | .0054 | 2180 | 328 | 5829 | 70.6 | 1282 | 903 | 5180 |
| 2057 | 2076 | 1051 | 1058 | 66.1 | 1716 | .0074 | 3080 | 1010 | 6259 | 79.6 | 199[illegible] | 1067 | 6220 |
| 2409 | 2443 | 1230 | 1228 | 72.8 | 2538 | .0100 | 4016 | 1748 | 6702 | 87.5 | 2957 | 1224 | 7340 |
| 2723 | 2750 | 1380 | 1373 | 77.9 | 3323 | .0121 | 4839 | 2401 | 7075 | 93.7 | 3861 | 1371 | 8290 |
| 2882 | 2903 | 1454 | 1448 | 80.4 | 3785 | .0134 | 5289 | 2784 | 7284 | 96.7 | 4379 | 1448 | 8830 |
| 2994 | 3007 | 1510 | 1504 | 82.1 | 4086 | .0143 | 5539 | 3007 | 7410 | 98.9 | 4760 | 1497 | 9150 |
| 3115 | 3117 | 1565 | 1562 | 83.6 | 4406 | .0150 | 5878 | 3305 | 7596 | 100.5 | 5124 | 1558 | 9540 |
| 3262 | 3256 | 1648 | 1652 | 84.9 | 4953 | .0167 | 6252 | 3614 | 7809 | 102.8 | 5784 | 1641 | 9980 |

TABLE II. - REYNOLDS NUMBER INDEX VARIATION WITH FLIGHT MACH NUMBER AND ALTITUDE

[Ram-pressure recovery, 1.00.]

| Altitude (ft) | Flight Mach number $M_0$ | $\delta$ | $\theta$ | $\varphi$ | Reynolds number index $\delta/\varphi\sqrt{\theta}$ |
|---|---|---|---|---|---|
| 0 | 0 | 1.000 | 1.000 | 1.000 | 1.000 |
| | .1 | 1.007 | 1.002 | 1.002 | 1.004 |
| | .2 | 1.028 | 1.008 | 1.006 | 1.018 |
| | .3 | 1.064 | 1.018 | 1.013 | 1.041 |
| | .4 | 1.117 | 1.032 | 1.023 | 1.075 |
| | .5 | 1.186 | 1.050 | 1.036 | 1.117 |
| | .6 | 1.276 | 1.072 | 1.051 | 1.173 |
| | .7 | 1.387 | 1.098 | 1.069 | 1.238 |
| | .8 | 1.524 | 1.128 | 1.090 | 1.316 |
| | .9 | 1.691 | 1.162 | 1.117 | 1.404 |
| | 1.0 | 1.893 | 1.200 | 1.141 | 1.516 |
| 5,000 | 0 | 0.8318 | 0.9657 | 0.9753 | 0.8679 |
| | .1 | .8374 | .9676 | .9764 | .8718 |
| | .2 | .8554 | .9734 | .9809 | .8839 |
| | .3 | .8862 | .9830 | .9875 | .9041 |
| | .4 | .9291 | .9965 | .9973 | .9333 |
| | .5 | .9868 | 1.014 | 1.010 | .9703 |
| | .6 | 1.061 | 1.035 | 1.025 | 1.018 |
| | .7 | 1.154 | 1.060 | 1.044 | 1.073 |
| | .8 | 1.268 | 1.089 | 1.064 | 1.141 |
| | .9 | 1.407 | 1.122 | 1.086 | 1.223 |
| | 1.0 | 1.575 | 1.159 | 1.117 | 1.309 |
| 10,000 | 0 | 0.6881 | 0.9312 | 0.9491 | 0.7513 |
| | .1 | .6923 | .9331 | .9504 | .7541 |
| | .2 | .7075 | .9387 | .9549 | .7647 |
| | .3 | .7320 | .9480 | .9621 | .7814 |
| | .4 | .7684 | .9609 | .9714 | .8069 |
| | .5 | .8157 | .9776 | .9836 | .8388 |
| | .6 | .8776 | .9983 | .9989 | .8794 |
| | .7 | .9542 | 1.022 | 1.016 | .9291 |
| | .8 | 1.048 | 1.050 | 1.037 | .9859 |
| | .9 | 1.163 | 1.082 | 1.058 | 1.057 |
| | 1.0 | 1.302 | 1.117 | 1.083 | 1.137 |
| 15,000 | 0 | 0.5643 | 0.8969 | 0.9223 | 0.6461 |
| | .1 | .5681 | .8987 | .9233 | .6490 |
| | .2 | .5799 | .9040 | .9281 | .6572 |
| | .3 | .6002 | .9131 | .9347 | .6720 |
| | .4 | .6300 | .9256 | .9448 | .6931 |
| | .5 | .6692 | .9416 | .9570 | .7206 |
| | .6 | .7198 | .9615 | .9719 | .7553 |
| | .7 | .7826 | .9848 | .9891 | .7973 |
| | .8 | .8601 | 1.012 | 1.008 | .8482 |
| | .9 | .9542 | 1.042 | 1.031 | .9062 |
| | 1.0 | 1.068 | 1.076 | 1.055 | .9762 |
| 20,000 | 0 | 0.4596 | 0.8626 | 0.8960 | 0.5523 |
| | .1 | .4629 | .8644 | .8966 | .5553 |
| | .2 | .4726 | .8696 | .9016 | .5622 |
| | .3 | .4891 | .8780 | .9072 | .5754 |
| | .4 | .5132 | .8902 | .9172 | .5930 |
| | .5 | .5454 | .9058 | .9289 | .6170 |
| | .6 | .5865 | .9247 | .9440 | .6461 |
| | .7 | .6375 | .9470 | .9610 | .6817 |
| | .8 | .7004 | .9728 | .9798 | .7248 |
| | .9 | .7769 | 1.002 | 1.002 | .7746 |
| | 1.0 | .8700 | 1.035 | 1.026 | .8341 |
| 25,000 | 0 | 0.3710 | 0.8281 | 0.8682 | 0.4696 |
| | .1 | .3737 | .8299 | .8700 | .4715 |
| | .2 | .3814 | .8347 | .8740 | .4776 |
| | .3 | .3948 | .8430 | .8804 | .4884 |
| | .4 | .4145 | .8545 | .8891 | .5043 |
| | .5 | .4399 | .8696 | .9016 | .5233 |
| | .6 | .4731 | .8877 | .9151 | .5487 |
| | .7 | .5147 | .9092 | .9316 | .5794 |
| | .8 | .5657 | .9339 | .9515 | .6152 |
| | .9 | .6276 | .9620 | .9724 | .6581 |
| | 1.0 | .7023 | .9934 | .9950 | .7082 |
| 30,000 | 0 | 0.2968 | 0.7938 | 0.8414 | 0.3959 |
| | .1 | .2989 | .7954 | .8430 | .3975 |
| | .2 | .3052 | .8002 | .8469 | .4029 |
| | .3 | .3158 | .8081 | .8525 | .4121 |
| | .4 | .3315 | .8193 | .8621 | .4248 |
| | .5 | .3519 | .8335 | .8727 | .4416 |
| 30,000 | 0.6 | 0.3787 | 0.8509 | 0.8862 | 0.4633 |
| | .7 | .4118 | .8715 | .9029 | .4886 |
| | .8 | .4522 | .8954 | .9207 | .5190 |
| | .9 | .5019 | .9222 | .9416 | .5551 |
| | 1.0 | .5619 | .9524 | .9655 | .5964 |
| 35,000 | 0 | 0.2352 | 0.7595 | 0.8149 | 0.3312 |
| | .1 | .2368 | .7611 | .8164 | .3325 |
| | .2 | .2418 | .7655 | .8196 | .3372 |
| | .3 | .2502 | .7732 | .8257 | .3446 |
| | .4 | .2627 | .7838 | .8337 | .3559 |
| | .5 | .2789 | .7975 | .8443 | .3699 |
| | .6 | .3001 | .8141 | .8576 | .3878 |
| | .7 | .3262 | .8339 | .8727 | .4093 |
| | .8 | .3583 | .8566 | .8910 | .4346 |
| | .9 | .3977 | .8825 | .9111 | .4647 |
| | 1.0 | .4452 | .9112 | .9334 | .4997 |
| 40,000 | 0 | 0.1853 | 0.7572 | 0.8130 | 0.2619 |
| | .1 | .1866 | .7588 | .8141 | .2631 |
| | .2 | .1905 | .7632 | .8175 | .2667 |
| | .3 | .1972 | .7709 | .8239 | .2726 |
| | .4 | .2070 | .7815 | .8321 | .2814 |
| | .5 | .2198 | .7950 | .8430 | .2924 |
| | .6 | .2364 | .8118 | .8562 | .3065 |
| | .7 | .2570 | .8314 | .8714 | .3235 |
| | .8 | .2824 | .8539 | .8889 | .3438 |
| | .9 | .3134 | .8798 | .9090 | .3676 |
| | 1.0 | .3506 | .9085 | .9310 | .3951 |
| 45,000 | 0 | 0.1459 | 0.7572 | 0.8130 | 0.2062 |
| | .1 | .1469 | .7588 | .8141 | .2071 |
| | .2 | .1500 | .7632 | .8175 | .2100 |
| | .3 | .1552 | .7709 | .8239 | .2145 |
| | .4 | .1630 | .7815 | .8321 | .2216 |
| | .5 | .1730 | .7950 | .8430 | .2302 |
| | .6 | .1862 | .8118 | .8562 | .2414 |
| | .7 | .2024 | .8314 | .8714 | .2548 |
| | .8 | .2224 | .8539 | .8889 | .2708 |
| | .9 | .2467 | .8798 | .9090 | .2894 |
| | 1.0 | .2762 | .9085 | .9310 | .3112 |
| 50,000 | 0 | 0.1149 | 0.7572 | 0.8130 | 0.1624 |
| | .1 | .1157 | .7588 | .8141 | .1631 |
| | .2 | .1181 | .7632 | .8175 | .1654 |
| | .3 | .1223 | .7709 | .8239 | .1691 |
| | .4 | .1284 | .7815 | .8321 | .1746 |
| | .5 | .1362 | .7950 | .8430 | .1812 |
| | .6 | .1466 | .8118 | .8562 | .1900 |
| | .7 | .1594 | .8314 | .8714 | .2006 |
| | .8 | .1751 | .8539 | .8889 | .2132 |
| | .9 | .1943 | .8798 | .9090 | .2279 |
| | 1.0 | .2175 | .9085 | .9310 | .2451 |
| 55,000 | 0 | 0.0905 | 0.7572 | 0.8130 | 0.1279 |
| | .1 | .0911 | .7588 | .8141 | .1285 |
| | .2 | .0930 | .7632 | .8175 | .1302 |
| | .3 | .0963 | .7709 | .8239 | .1331 |
| | .4 | .1011 | .7815 | .8321 | .1374 |
| | .5 | .1073 | .7950 | .8430 | .1428 |
| | .6 | .1155 | .8118 | .8562 | .1497 |
| | .7 | .1255 | .8314 | .8714 | .1580 |
| | .8 | .1379 | .8539 | .8889 | .1679 |
| | .9 | .1530 | .8798 | .9090 | .1795 |
| | 1.0 | .1713 | .9085 | .9310 | .1930 |
| 60,000 | 0 | 0.0713 | 0.7572 | 0.8130 | 0.1008 |
| | .1 | .0717 | .7588 | .8141 | .1011 |
| | .2 | .0733 | .7632 | .8175 | .1026 |
| | .3 | .0758 | .7709 | .8239 | .1048 |
| | .4 | .0796 | .7815 | .8321 | .1082 |
| | .5 | .0845 | .7950 | .8430 | .1124 |
| | .6 | .0909 | .8118 | .8562 | .1178 |
| | .7 | .0988 | .8314 | .8714 | .1244 |
| | .8 | .1086 | .8539 | .8889 | .1322 |
| | .9 | .1205 | .8798 | .9090 | .1413 |
| | 1.0 | .1349 | .9085 | .9310 | .1520 |

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TABLE III. - PERFORMANCE DATA FOR EFFECT OF ENGINE-INLET TOTAL TEMPERATURE ON EXHAUST-GAS TOTAL TEMPERATURE

| Engine speed $N$ (rpm) | Altitude static pressure $p_0$ (lb/sq ft abs) | Engine-inlet total pressure $P_1$ (lb/sq ft abs) | Engine-inlet static pressure $p_1$ (lb/sq ft abs) | Engine-inlet total temperature $T_1$ (°R) | Nozzle-inlet total pressure $P_9$ (lb/sq ft abs) | Nozzle-inlet total temperature $T_9$ (°R) | Compressor-inlet air flow $W_{a,2}$ (lb/sec) | Engine fuel flow $W_{f,e}$ (lb/hr) | Net thrust $F_n$ (lb) | Corrected engine speed $N/\sqrt{\theta_1}$ (rpm) | Corrected exhaust-gas total temperature $T_9/\theta_1$ (°R) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7947 | 987 | 996 | 894 | 431 | 2102 | 1690 | 54.9 | 3485 | 3063 | 8718 | 2035 |
| 7947 | 970 | 1002 | 898 | 455 | 2027 | 1678 | 53.1 | 3260 | 2881 | 8487 | 1915 |
| 7947 | 972 | 999 | 901 | 481 | 1955 | 1681 | 51.1 | 3084 | 2696 | 8257 | 1814 |
| 7951 | 986 | 999 | 902 | 499 | 1908 | 1897 | 49.6 | 2979 | 2572 | 8110 | 1765 |
| 7953 | 989 | 991 | 895 | 520 | 1869 | 1713 | 48.3 | 2911 | 2490 | 7945 | 1710 |
| 7955 | 989 | 995 | 900 | 532 | 1853 | 1731 | 47.7 | 2875 | 2422 | 7855 | 1689 |

[redacted]

TABLE IV. - PERFORMANCE DATA FOR EFFECT OF ENGINE-INLET RAM-PRESSURE RATIO ON CORRECTED EXHAUST-GAS TOTAL TEMPERATURE

| Engine speed $N$ (rpm) | Altitude static pressure $p_0$ (lb/sq ft abs) | Engine-inlet total pressure $P_1$ (lb/sq ft abs) | Engine-inlet static pressure $p_1$ (lb/sq ft abs) | Engine-inlet total temperature $T_1$ (°R) | Nozzle-inlet total pressure $P_9$ (lb/sq ft abs) | Nozzle-inlet total temperature $T_9$ (°R) | Compressor-inlet air flow $W_{a,2}$ (lb/sec) | Engine fuel flow $W_{f,e}$ (lb/hr) | Net thrust $F_n$ (lb) | Corrected engine speed $N/\sqrt{\theta_1}$ (rpm) | Corrected exhaust-gas total temperature $T_9/\theta_1$ (°R) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7953 | 1294 | 1332 | 1204 | 512 | 2560 | 1741 | 65.3 | 4022 | 3460 | 8009 | 1765 |
| 7951 | 1223 | 1335 | 1207 | 513 | 2545 | 1731 | 65.3 | 3975 | 3229 | 7999 | 1752 |
| 7955 | 1173 | 1339 | 1211 | 512 | 2544 | 1729 | 65.4 | 3973 | 3175 | 8011 | 1753 |
| 7945 | 1128 | 1340 | 1211 | 511 | 2540 | 1719 | 65.7 | 3948 | 3092 | 8009 | 1747 |
| 7947 | 1042 | 1342 | 1213 | 512 | 2545 | 1718 | 66.0 | 3948 | 3040 | 8003 | 1742 |
| 7951 | 1290 | 1331 | 1207 | 529 | 2497 | 1758 | 63.3 | 3902 | 3307 | 7875 | 1725 |
| 7947 | 1220 | 1336 | 1212 | 528 | 2493 | 1743 | 83.6 | 3874 | 3077 | 7879 | 1713 |
| 7953 | 1169 | 1337 | 1211 | 529 | 2483 | 1741 | 63.5 | 3829 | 3010 | 7877 | 1708 |
| 7947 | 1120 | 1340 | 1214 | 529 | 2484 | 1738 | 63.7 | 3865 | 2985 | 7872 | 1705 |
| 7951 | 1083 | 1333 | 1207 | 529 | 2478 | 1732 | 63.8 | 3865 | 2922 | 7875 | 1699 |
| 7943 | 1047 | 1340 | 1212 | 529 | 2479 | 1728 | 64.0 | 3856 | 2888 | 7868 | 1695 |
| 7945 | 1455 | 1533 | 1394 | 536 | 2842 | 1743 | 71.7 | 4330 | 3562 | 7818 | 1688 |
| 7951 | 1464 | 1614 | 1467 | 537 | 2981 | 1727 | 75.7 | 4502 | 3569 | 7817 | 1669 |
| 7953 | 1471 | 1762 | 1597 | 536 | 3256 | 1726 | 83.1 | 4933 | 3790 | 7826 | 1671 |
| 7951 | 1468 | 1896 | 1713 | 537 | 3486 | 1712 | 89.7 | 5300 | 3987 | 7817 | 1655 |
| 7720 | 1764 | 1818 | 1659 | 531 | 3304 | 1669 | 84.0 | 4779 | 4228 | 7632 | 1631 |
| 7737 | 1726 | 1815 | 1655 | 536 | 3273 | 1673 | 82.2 | 4710 | 4086 | 7613 | 1620 |
| 7722 | 1691 | 1815 | 1658 | 535 | 3250 | 1657 | 82.0 | 4638 | 4001 | 7605 | 1607 |
| 7727 | 1597 | 1819 | 1658 | 534 | 3247 | 1653 | 82.3 | 4628 | 3922 | 7617 | 1607 |
| 7724 | 1516 | 1824 | 1659 | 534 | 3247 | 1642 | 82.8 | 4618 | 3832 | 7614 | 1596 |
| 7727 | 1441 | 1826 | 1659 | 533 | 3256 | 1642 | 83.3 | 4648 | 3800 | 7625 | 1599 |

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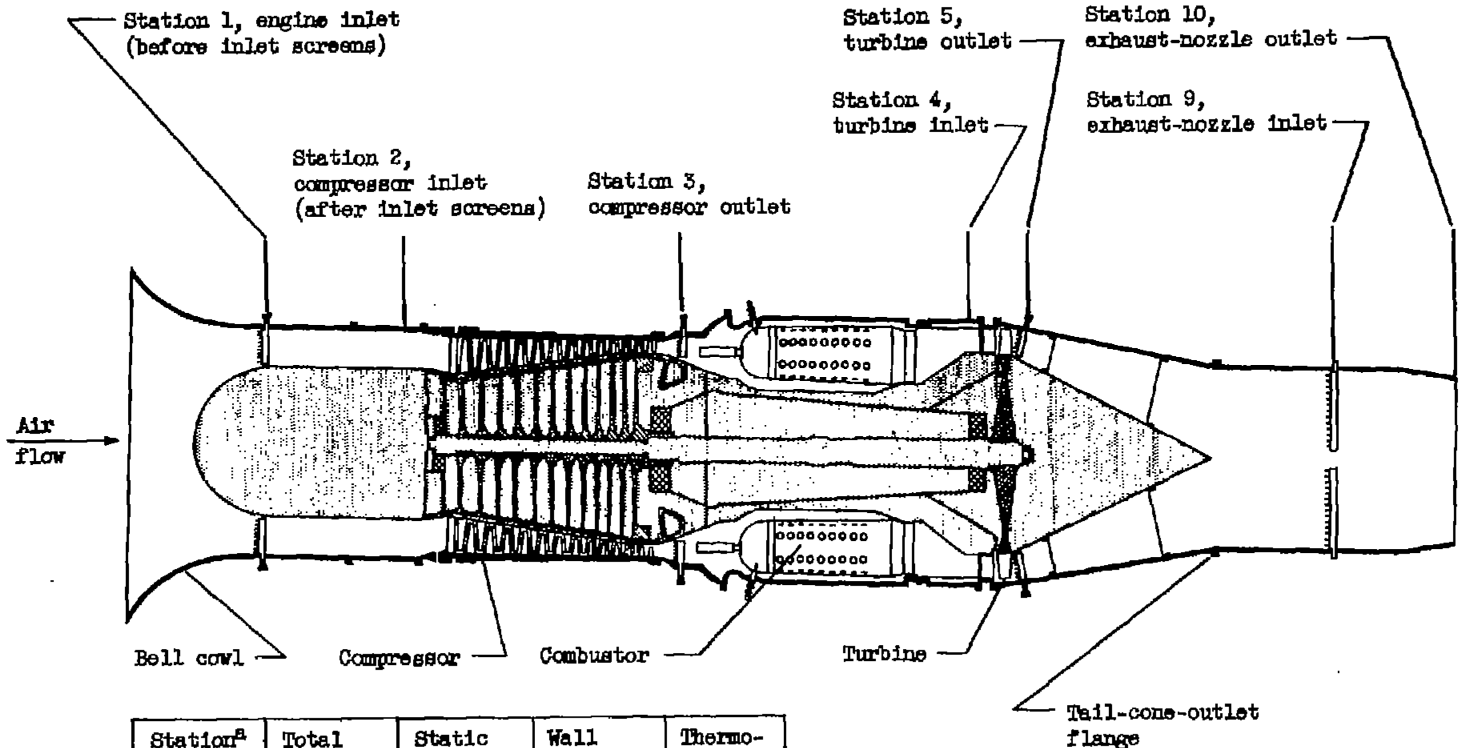


| Station[a] | Total pressure tubes | Static pressure tubes | Wall static orifices | Thermo-couples |
|---|---|---|---|---|
| 1 | 24 | 4 | 6 | 12 |
| 3 | 12 | 0 | 2 | 12 |
| 4 | 8 | 0 | 0 | 8 |
| 5 | 15 | 0 | 3 | 12 |
| 9 | 25 | 0 | 5 | 41 |

[a]No instrumentation at station 2.

Figure 1. - Cross section of engine showing location of instrumentation.

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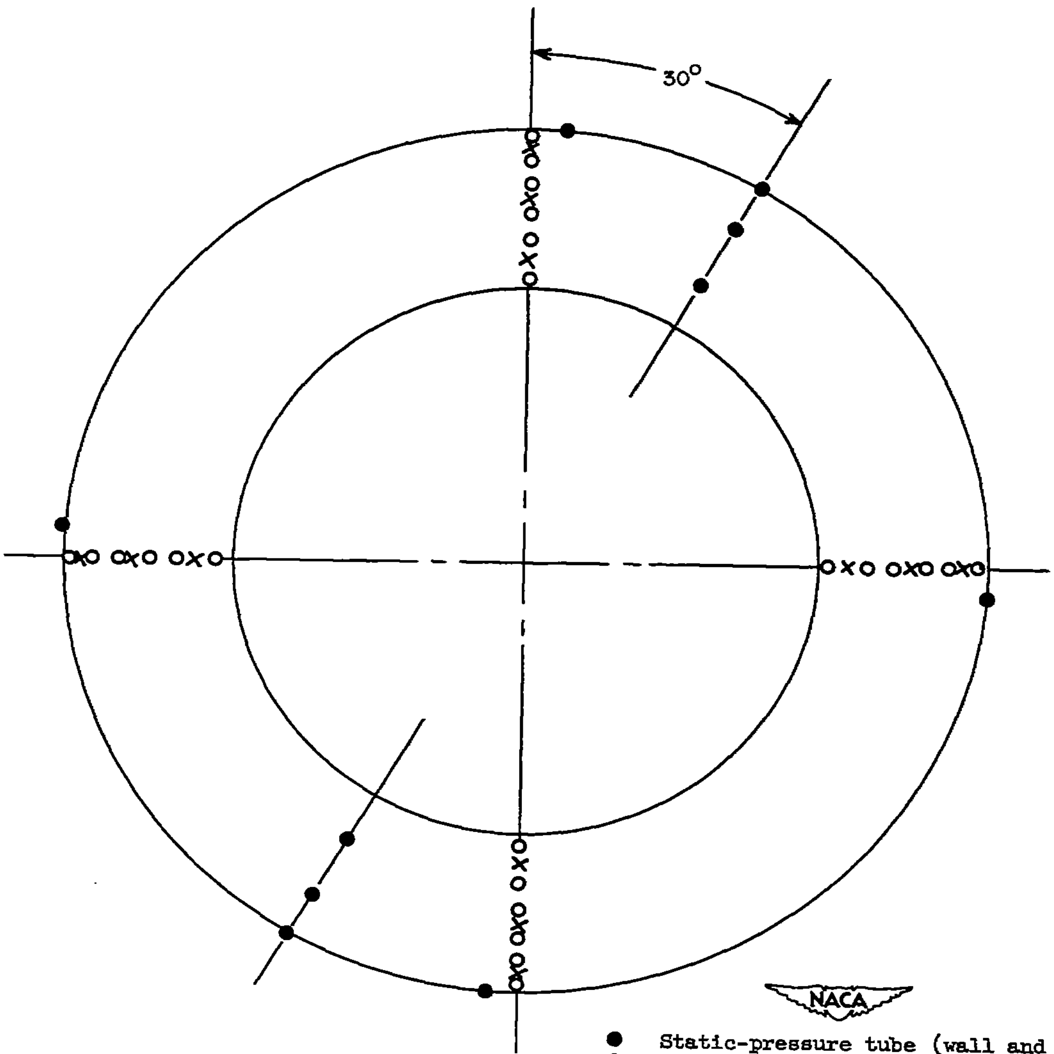
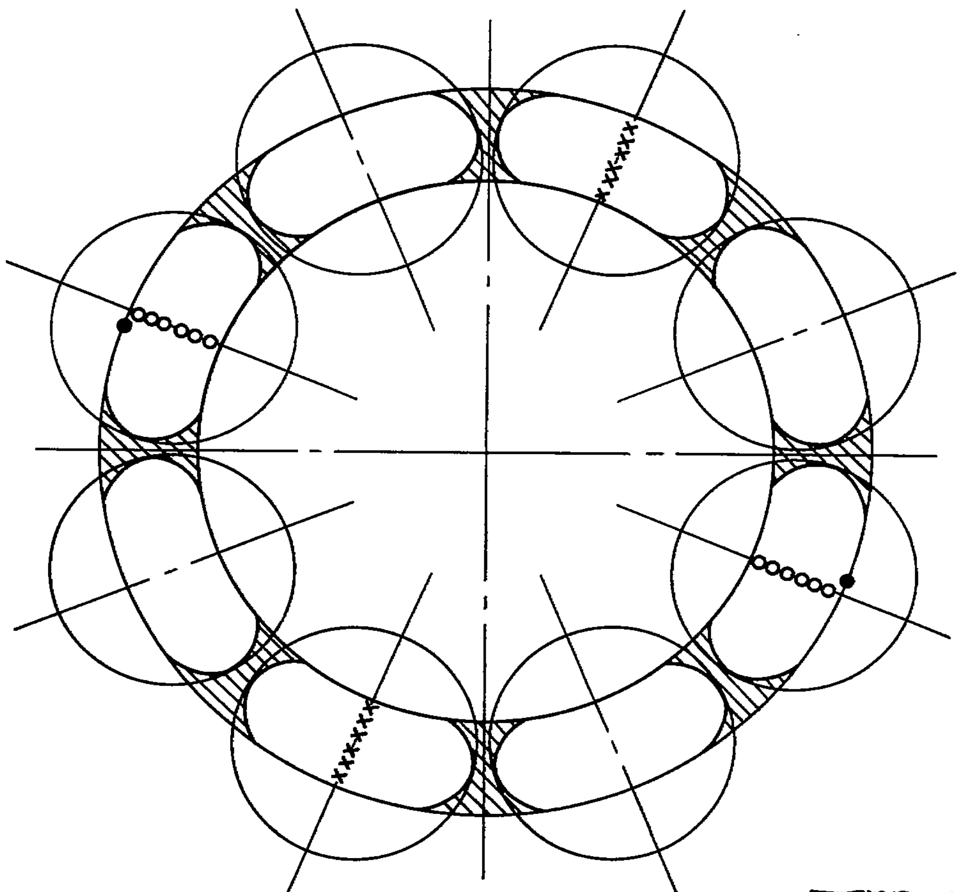



● Static-pressure tube (wall and rake)
O Total-pressure tube
X Thermocouple

(a) Instrumentation at engine inlet, station 1, 21 inches upstream of leading edge of compressor-inlet guide vanes. Viewed from upstream.

Figure 2. - Instrumentation sketches of various measuring stations.

2625

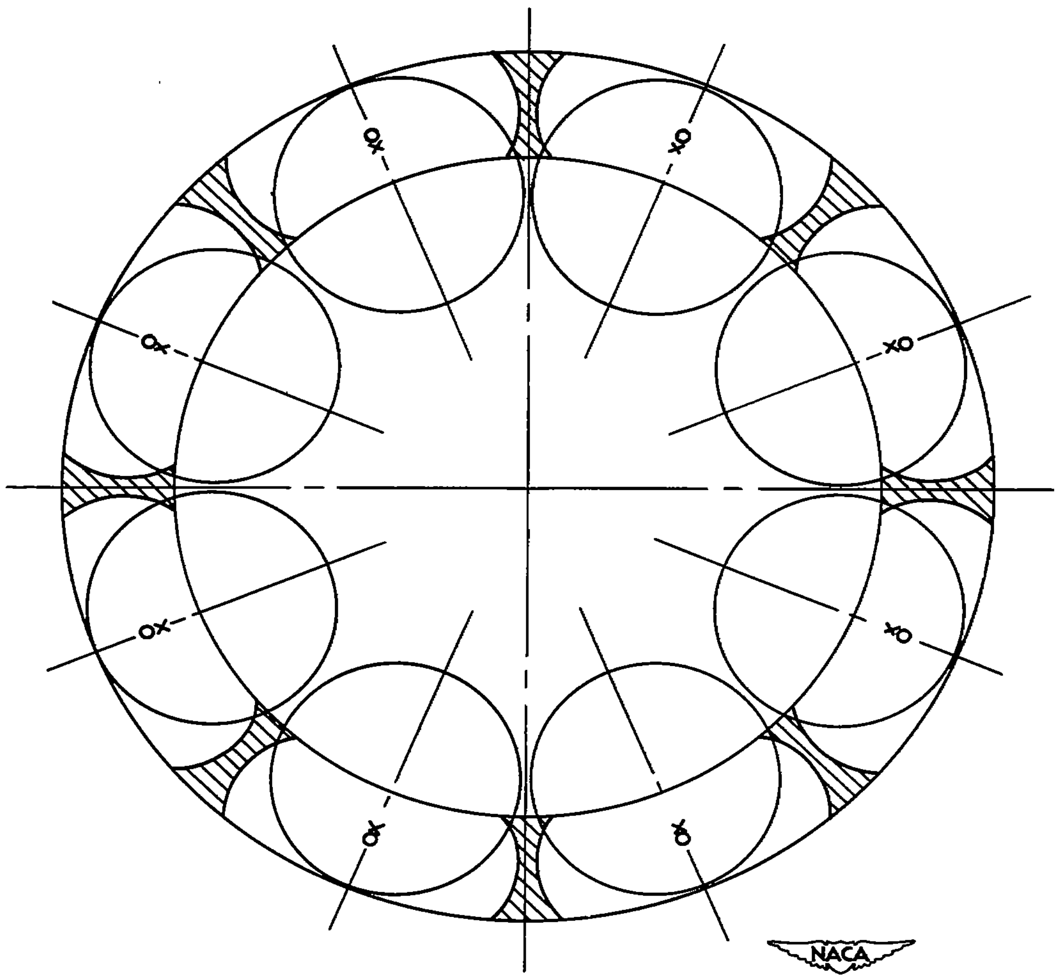


● Wall static-pressure tube
○ Total-pressure tube
× Thermocouple

(b) Instrumentation at compressor outlet~~,~~ station 3, 2 inches downstream of trailing edge of compressor-outlet guide vanes. Viewed from upstream.

Figure 2. - Continued. Instrumentation sketches of various measuring stations.

2625

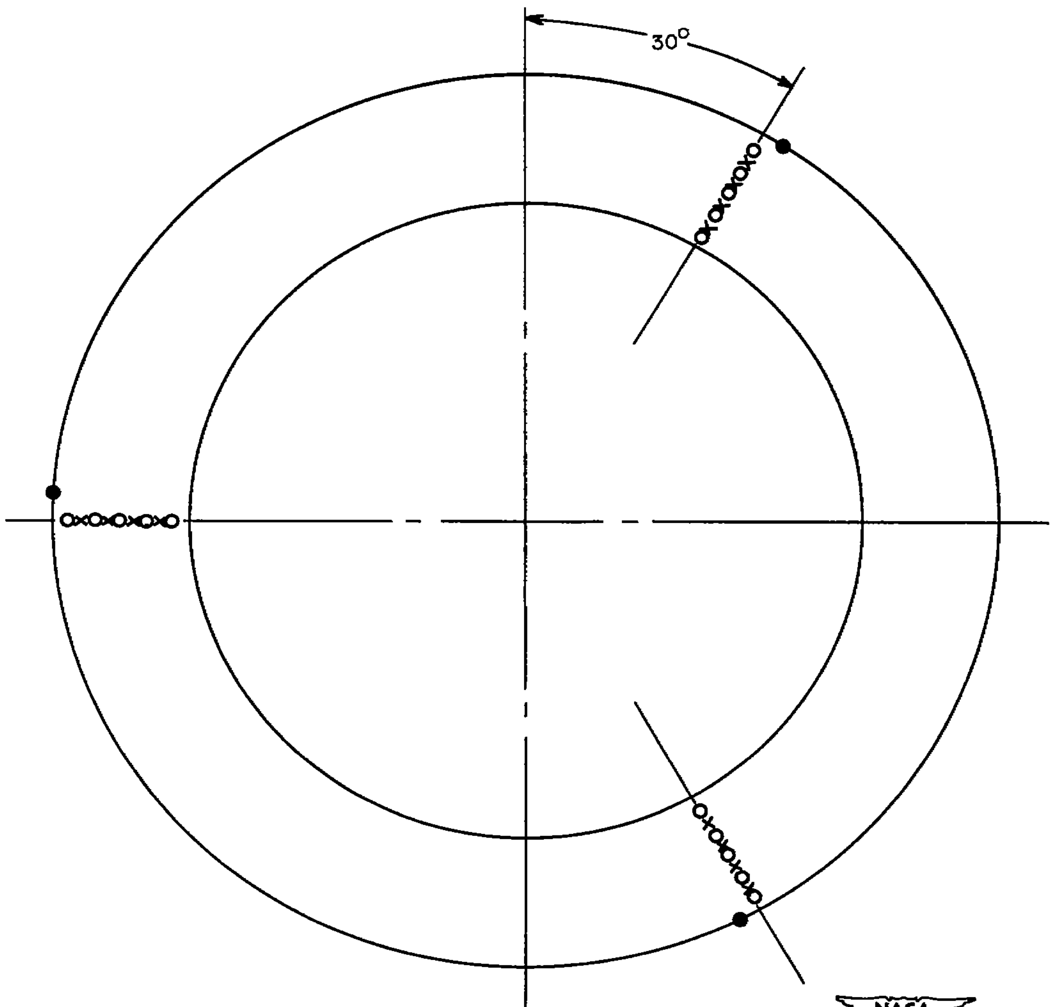


O Total-pressure tube
X Thermocouple

(c) Instrumentation at turbine inlet, station 4, $1\frac{3}{4}$ inches upstream of leading edge of turbine-inlet guide vanes. Viewed from upstream.

Figure 2. - Continued. Instrumentation sketches of various measuring stations.

2625

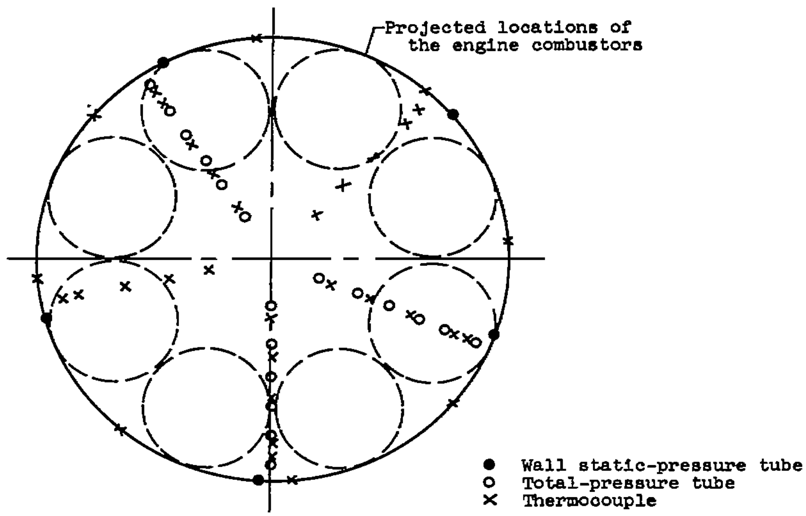



● Wall static-pressure tube
○ Total-pressure tube
× Thermocouple

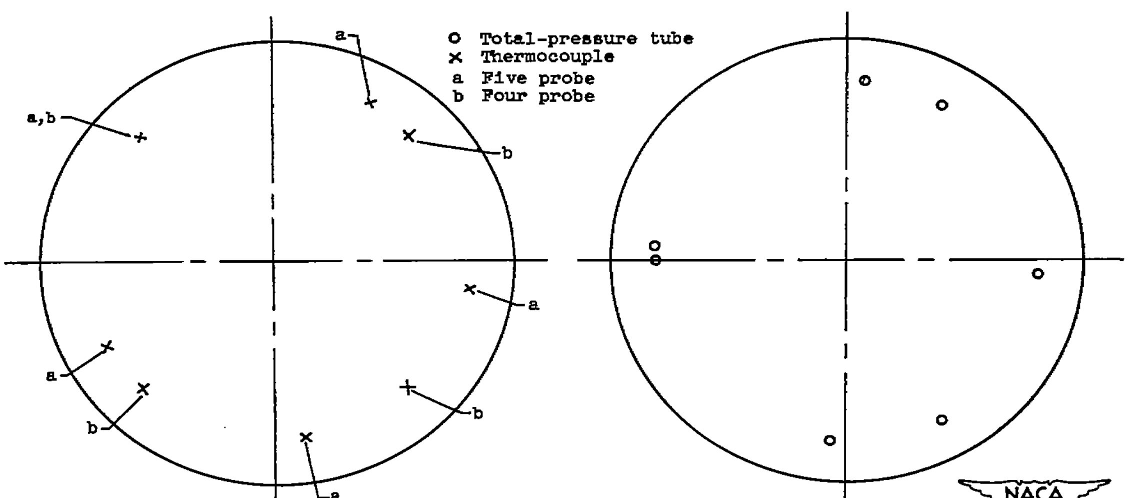
(d) Instrumentation at turbine outlet, station 5, $2\frac{3}{4}$ inches downstream of trailing edge of turbine blades. Viewed from upstream.

Figure 2. - Continued. Instrumentation sketches of various measuring stations.

2625




(e) NACA instrumentation at nozzle inlet, station 9, 15.15 inches downstream of tail-cone-outlet flange. Viewed from upstream.




Engine manufacturer's instrumentation

Air frame manufacturer's instrumentation

(f) Engine and air frame manufacturers' instrumentation at nozzle inlet, station 9, 15.15 inches downstream of tail-cone-outlet flange. Viewed from upstream.

Figure 2. - Concluded. Instrumentation sketches of various measuring stations.

2625

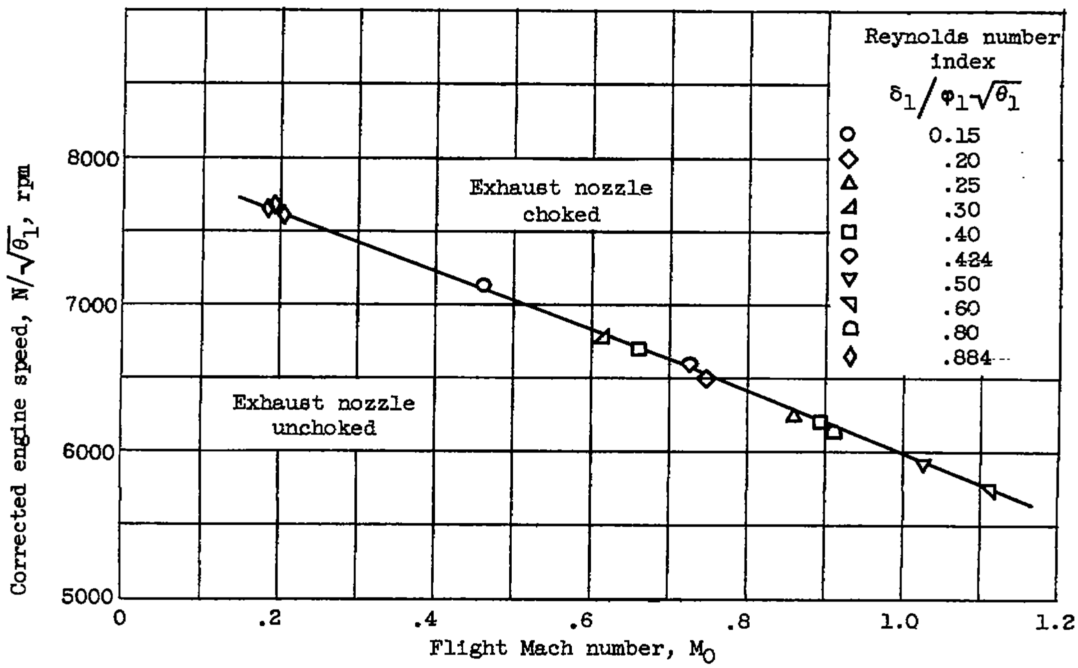



Figure 3. - Minimum corrected engine speeds at which critical flow existed in the exhaust nozzle.

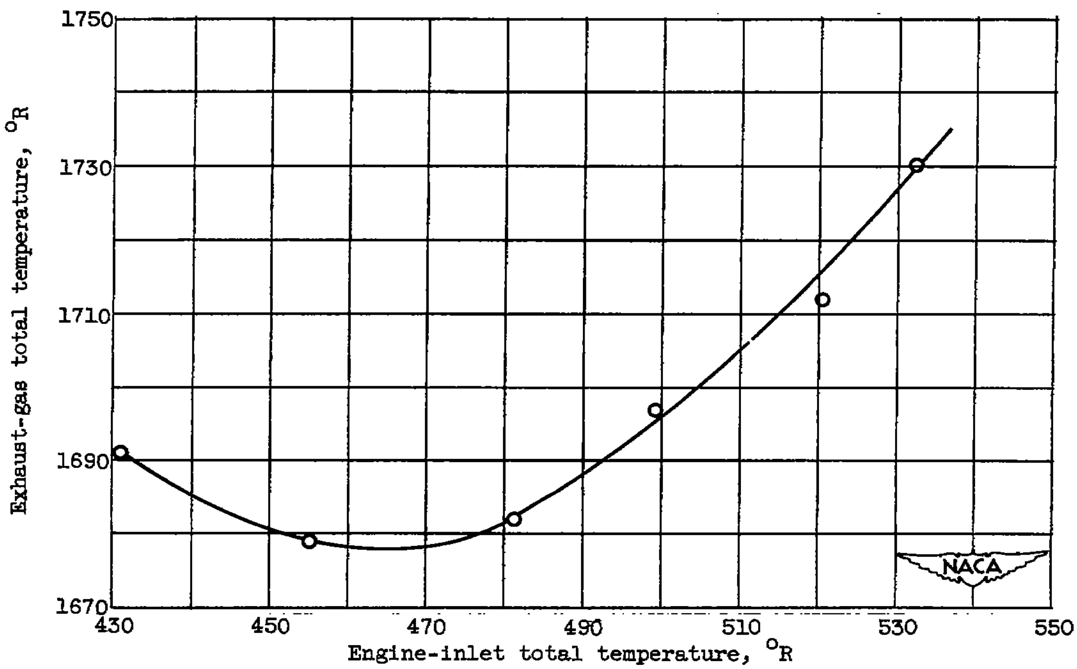



Figure 4. - Effect of engine-inlet total temperature on exhaust-gas total temperature. Engine speed, 7950 rpm; altitude, 20,000 feet; flight Mach number, 0.2.

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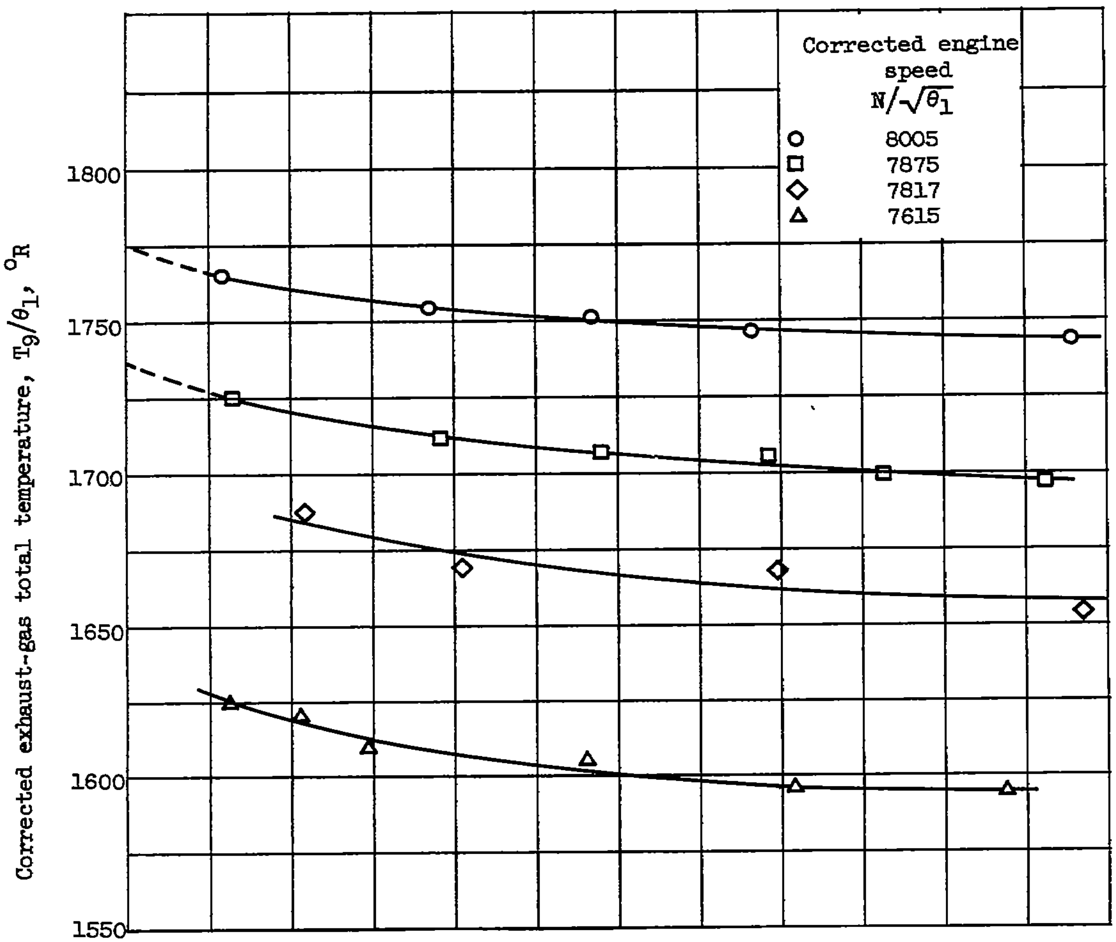
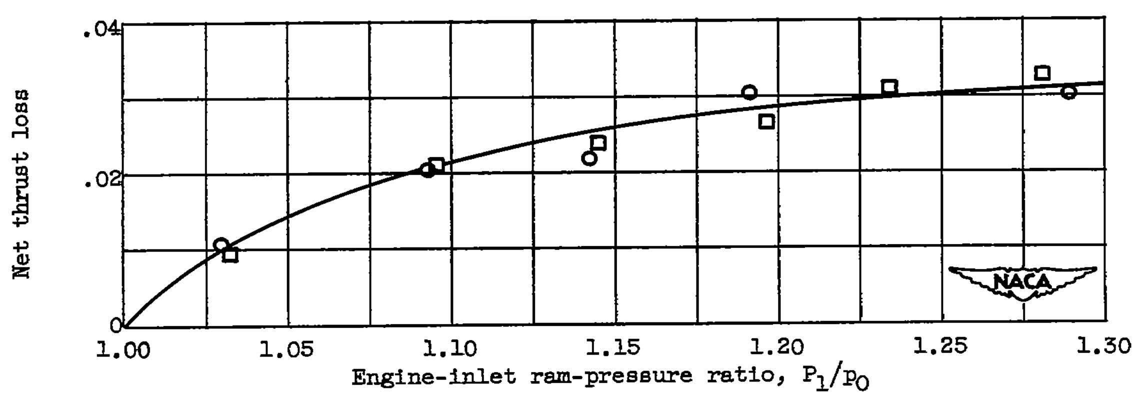



(a) Corrected exhaust-gas total temperature.




(b) Net thrust loss.

Figure 5. - Effect of engine-inlet ram-pressure ratio on corrected exhaust-gas total temperature and net thrust loss for various corrected engine speeds.

[redacted]

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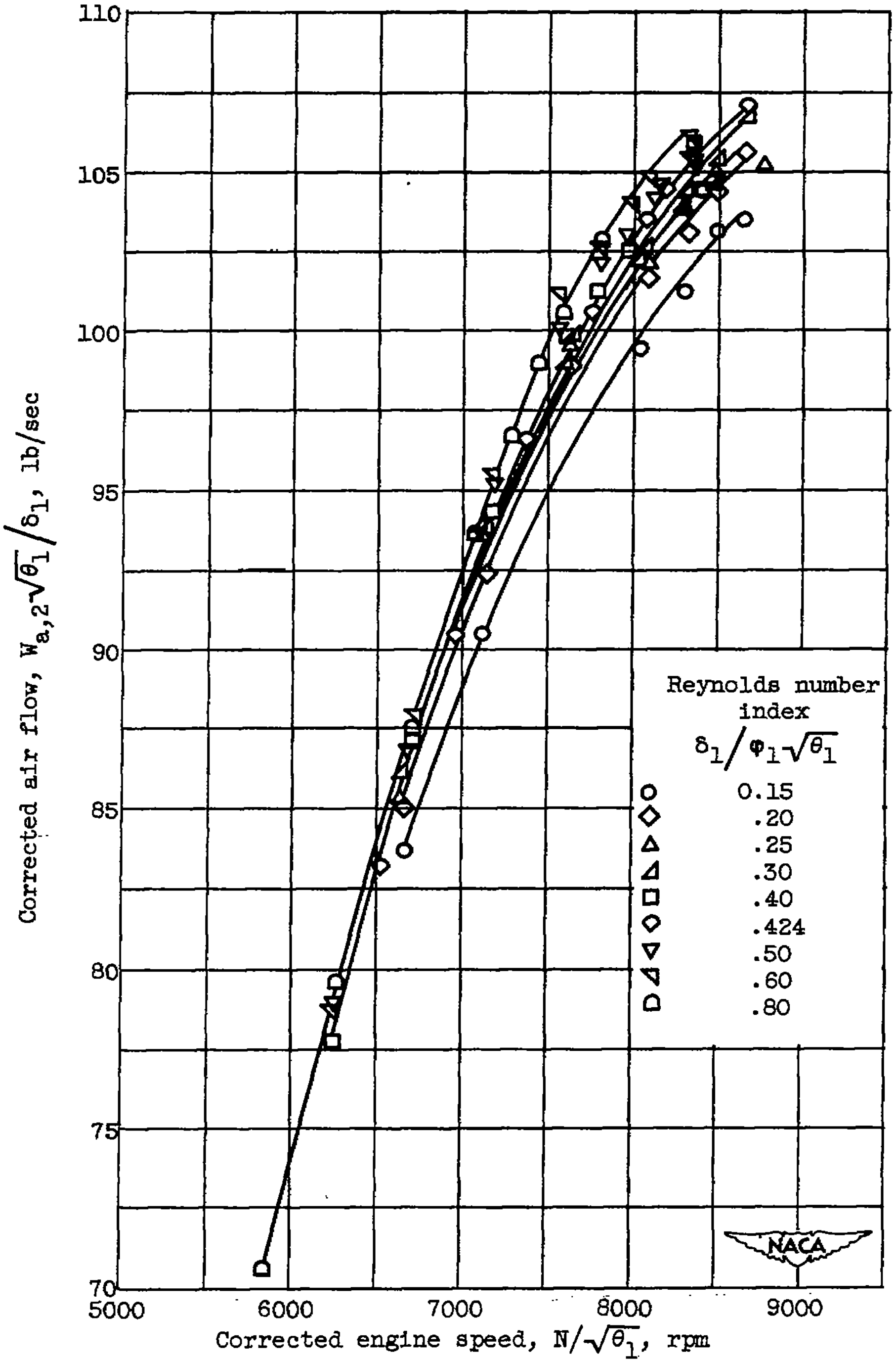


Figure 6. - Variation of corrected air flow with corrected engine speed for various Reynolds number indices.

2625

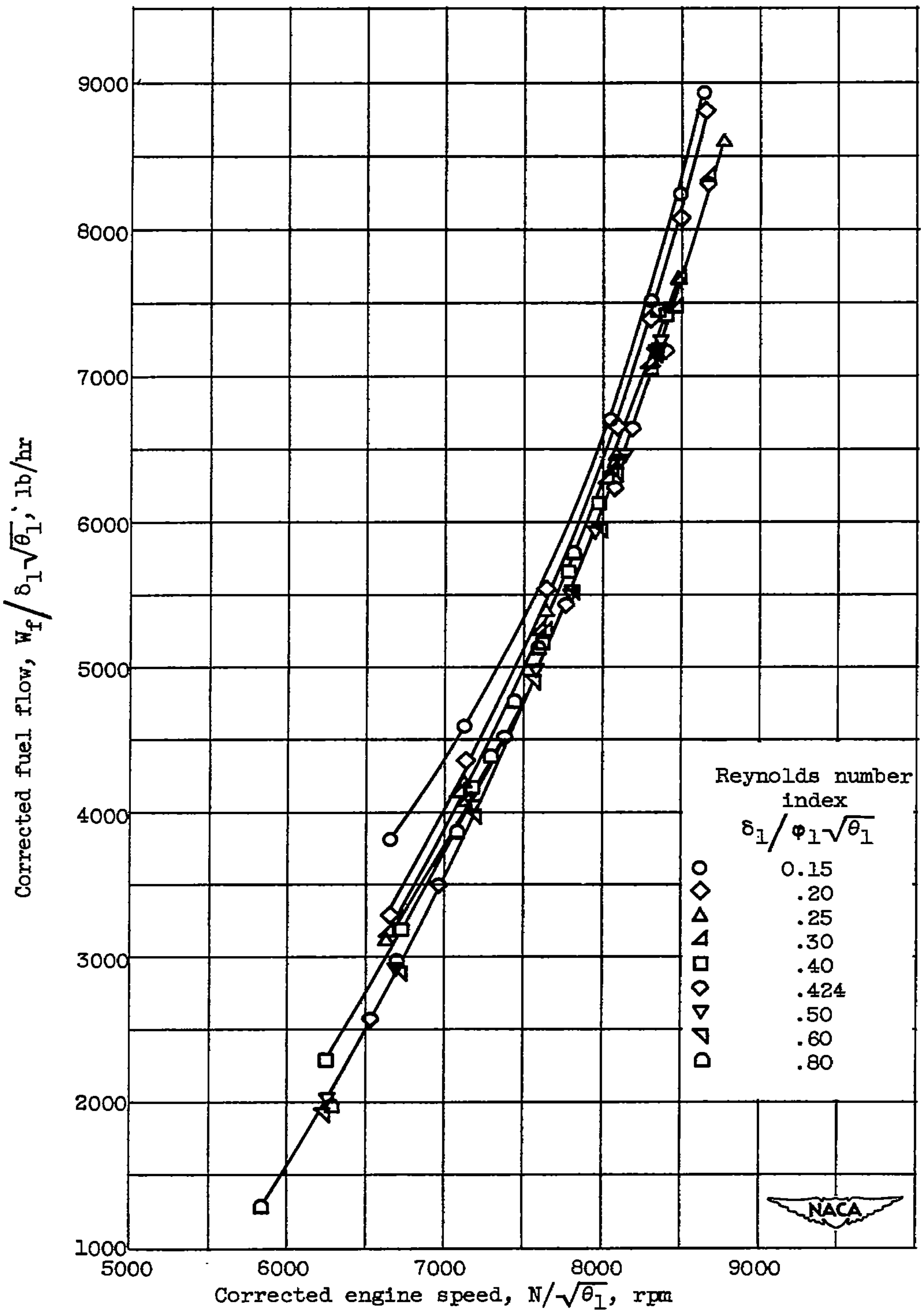


Figure 7. - Variation of corrected fuel flow with corrected engine speed for various Reynolds number indices.

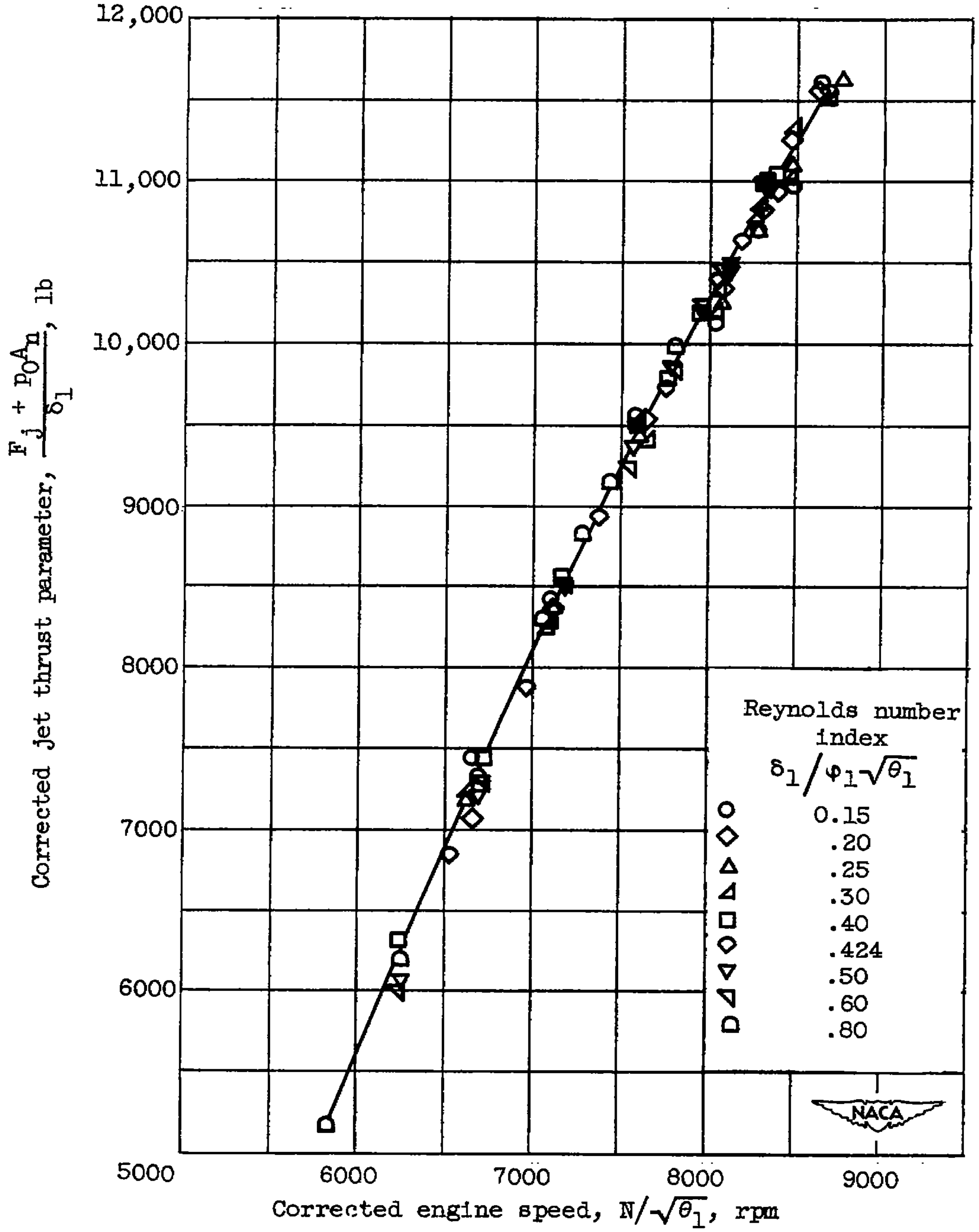


Figure 8. - Variation of corrected jet thrust parameter with corrected engine speed for various Reynolds number indices.

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[redacted]

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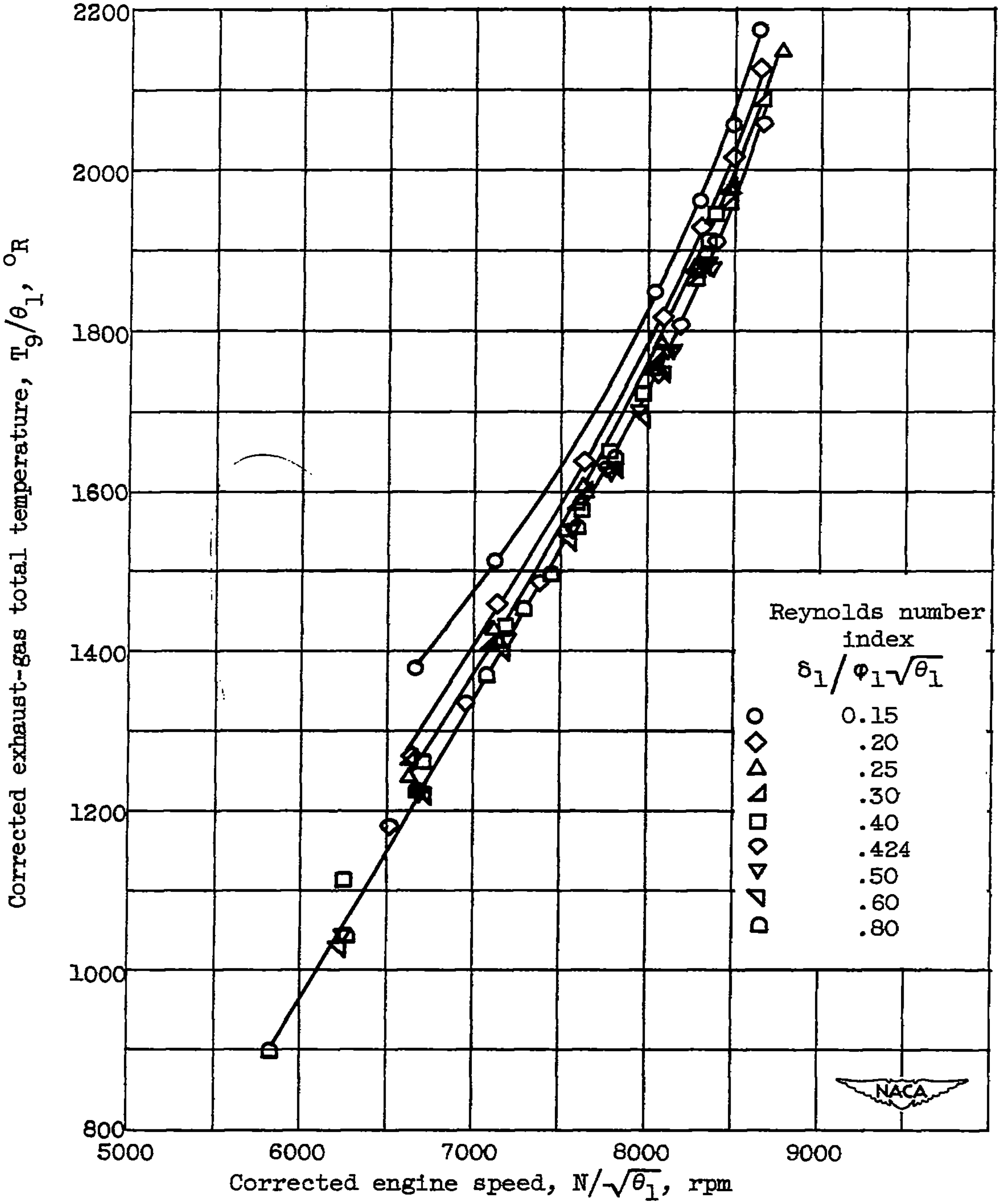


Figure 9. - Variation of corrected exhaust-gas total temperature with corrected engine speed for various Reynolds number indices.

[redacted]

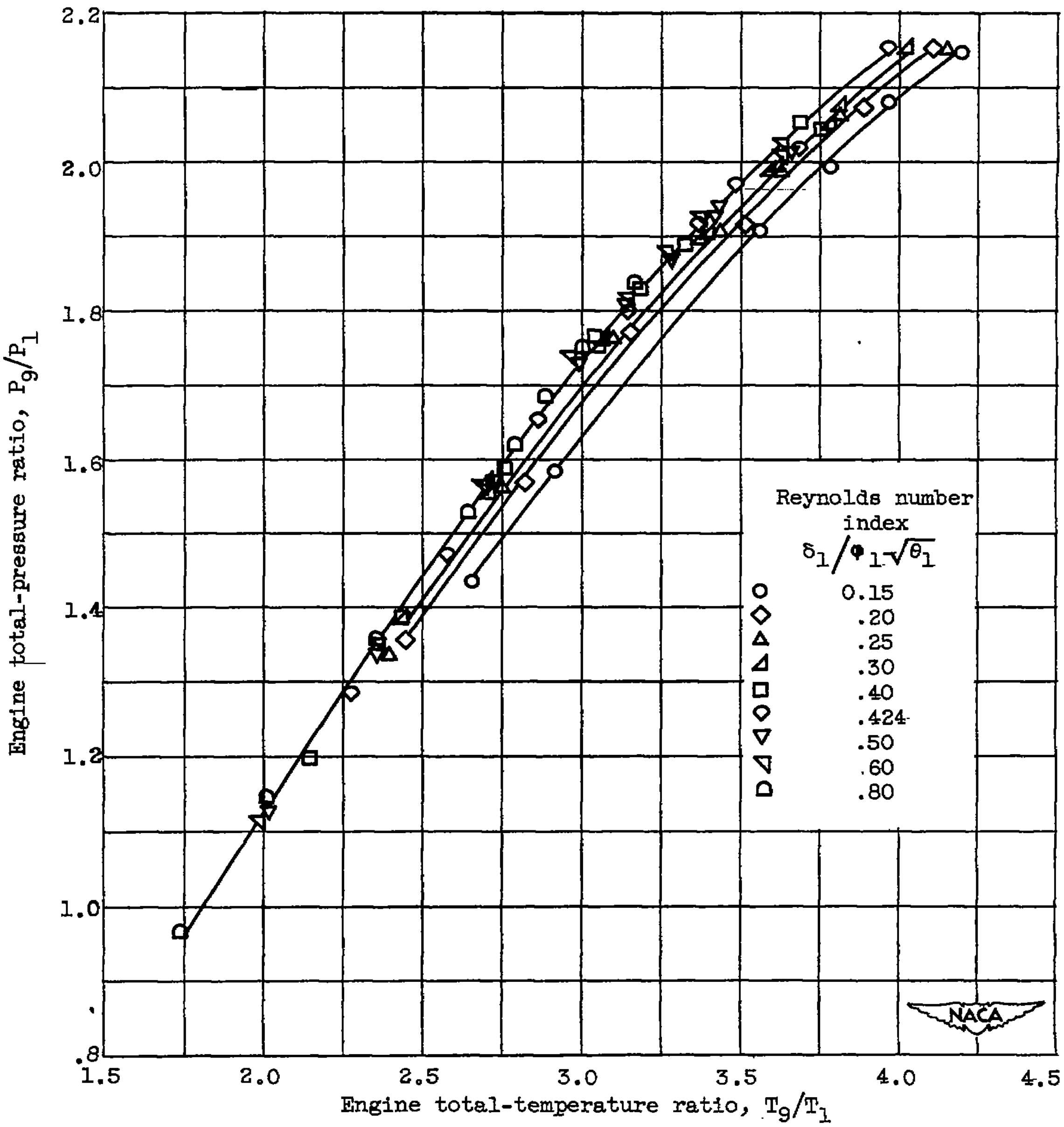


Figure 10. - Variation of engine total-pressure ratio with engine total-temperature ratio for various Reynolds number indices.

2625

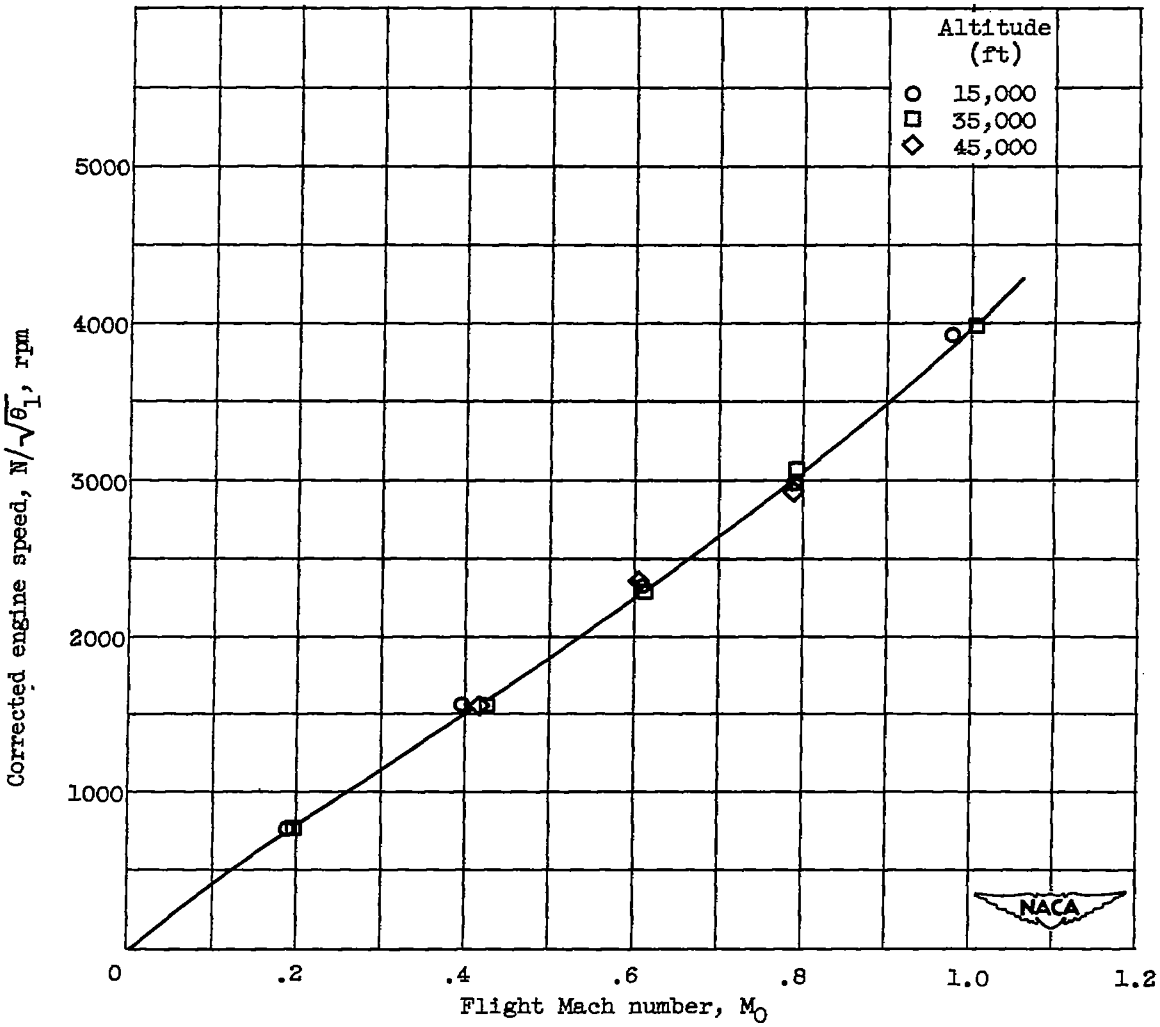


Figure 11. - Variation of corrected windmilling engine speed with flight Mach number at three altitudes.

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SECURITY INFORMATION

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